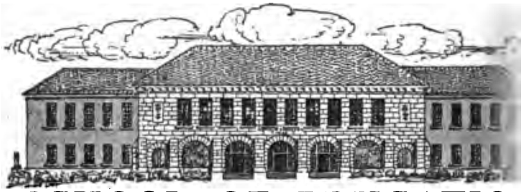
STATE SERIES

ADVANCED LESSONS IN HUMAN PHYSIOLOGY



INDIANA STATE SERIES

ADVANCED LESSONS

IN

HUMAN PHYSIOLOGY

A TREATISE OF THE HUMAN BODY, INCLUDING AN ACCOUNT OF ITS STRUCTURE, ITS FUNCTIONS, AND THE LAWS OF HEALTH

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PREFACE.

THIS book has been prepared for use as an elementary text-book in the schools.

It has been the constant aim of the author to have even this elementary view of the human body taken from a scientific standpoint. The immense contributions to the science of Physiology in recent years have entirely changed the tone and spirit of physiological thought and discussion, as is shown in the most recent great works on the subject. An elementary work should partake sufficiently of this spirit to introduce even the young student into its influence.

To take the facts which are a part of the structure of a well-organized science, and make such use of them as to give no hint of the existence of the science, is not only of little good, but is really an unnecessary waste of time. This is done when many facts in regard to the structure and functions of the Human Body are learned as isolated things, simply as a class exercise, or even through curiosity or interest in them as parts of the human body.

On the completion of even an elementary course in Physiology, the human body should be seen as an organism whose activities are conditioned by the fundamental laws that are recognized in the sciences of Physics and Chemistry; and, further, that the very complex body is, in all its

parts, so interrelated and coördinated as to be able to manage the complex activities of the body seen as a whole, by analyzing its processes and distributing them among its parts, and thus accomplishing most perfectly the whole of its purpose.

Again, in recent years the human body has come to be seen more and more clearly to have many things in common with all other living organisms. Too much in the past the study of Human Physiology has been conducted as something entirely separated from sciences of which it is really a part. The early study of the human body should bring one to see that much that he learns of its structure and activity is universal through the Animal Kingdom. In other words, the study of the human body is the study of Biology, and it adds to the clearness of its conceptions and much increases its interest to recognize and make use of this fact.

The surest and only foundation for correct hygienic conceptions and methods is a scientific spirit, and a correct view of the body working as a whole. Much of the writing and discussion of hygiene and sanitary matters lacks this basis. And where such diverse opinions are promulgated, it is especially desirable that a basis for a correct judgment in distinguishing between what is and what is not sound be formed as early as possible.

Physiology being one of the very few natural science subjects which are taught in most of our public schools, it should be made to furnish the special educational advantages now generally conceded to natural science subjects. This can only come when the subject is treated as a science.

It is thought that such a treatment of Physiology is too

difficult for young students. While there is a vast amount in the science that is too difficult to introduce into such a work, yet the author's experience with such pupils is that elementary facts in the science are not so difficult of presentation and reception when given in their real relations as when given without this reference. Placing things in their real relation constitutes science.

It has long ago been demonstrated that the true method of teaching natural science subjects demands the personal contact with at least enough of the objects of the study to form clear conceptions, to serve as a true basis for thinking and speaking correctly in the terms of the science.

In recognition of this view, at the close of each chapter a few simple directions have been added to aid the student and teacher in making such observations as will aid in the work. These directions are simply suggestive of what may be considerably extended. A long experience has assured the author that this method is not only practicable but eminently desirable, and he would strongly urge the faithful carrying out of at least a large number of these directions.

These methods are no longer a novelty. They are essential in every well-conducted biological laboratory, and are used by a large number of the most successful teachers in the elementary schools. Teachers would do well to furnish themselves with some of the more extensive hand-books on physiological experimentation and dissection now easily obtainable.

The author acknowledges with pleasure the aid he has received in reading the manuscript of the book and in offering various valuable suggestions, and in reading the proofs, from Mr. Barton W. Evermann, Professor of Biology

in the *Indiana State Normal School;* also similar aid from Mr. W. W. Norman, Assistant in Biology in *DePauw University*, and Mr. C. W. Greene, Instructor in Physiology in the *DePauw Preparatory School.*

Most of the diagrams in this work were drawn by Mr. Edward Hughes under the author's direction. Figures 80 and 81 are copied from Lang's *Vergleichende Anatomie.* Figures 61 and 83 are modified from cuts used in *Landois and Stirling's Physiology.*

Teachers are urged to procure for the further discussion of the subjects treated in this little book, such advanced works as those by Foster, Martin, and Landois and Stirling.

OLIVER P. JENKINS.

DEPAUW UNIVERSITY,
May 5, 1891.

HUMAN PHYSIOLOGY.

CHAPTER I.

THE STUDY OF THE HUMAN BODY.

The Human Body in Action.—In such a common action as reaching out the hand and picking up an apple from the table, it is a pleasure to note the beautiful adaptation of the arm and hand to the action. The apple can be firmly held and turned in any direction, and be carried to any point in reach of the arm, all with great precision. It would take great labor and thought to invent a piece of machinery that would do half as well.

If even a superficial view be taken of other actions which the apple might occasion, such as walking a distance, climbing a tree, or throwing a club for it, and, after obtaining it, of tasting, eating, and digesting it, and many others that might be given, the wonder for the beautiful adaptations of the parts of the body to the accomplishment of these complex actions would increase.

The observations may be still further extended to include the great number of actions which the human body performs in its daily contact with thousands of objects, the sum of which actions makes up the life of the body.

Then we would see in the body as a whole an organism wonderfully adapted to the conditions of its existence. The elementary study of the body and its parts, and of how these

parts are adapted to the work necessary for its existence in its surrounding conditions, is the object set before us in this book.

Other Organisms.—The human body is but one of the very large number of organisms existing on the earth which show that kind of activity called life.

Living things—that is, plants and animals—have peopled the whole surface of the earth with innumerable forms. Among the plants, the forms range from the giant trees of California and the immense spreading banyans of India, through all forms of forest trees, creeping vines, the thick cactus, the slender grass, the velvety moss, the flat lichen, down to the microscopic single-celled plant floating in the water.

With the animals, the forms are no less numerous, and the range through both form and size is very great. These myriads of forms are so many adaptations of living organisms to the many conditions of life in which they are found.

For example, the squirrel in all its parts is adapted to life in the tops of trees; the mole, to a life spent in the ground; all fishes to water, one kind to deep holes, another to shallow ripples; different kinds of birds, to different kinds of positions; some worms, for burrowing in the ground; some insects to a life in the open air, and others to tunneling through the trunks of trees.

These few examples but illustrate to a very limited extent how forms are adapted to conditions surrounding them. In reality, the different conditions are as numerous as the forms of plants and animals. The conditions range through all shades of climate; they vary with different positions offered by hill, mountain, valley, and plain; by a moist, dry, warm, or cold atmosphere; by fresh, salt, shallow, deep, clear, or muddy water; or by positions in the nooks or crannies in the rocks, under and over rotting logs, in the tops of trees, in the holes in the ground, or in the countless forms of foods.

Each living form is an answer to the problem of how a living organism can maintain its existence in the position in which it is found.

Biology.—The group of sciences which have for their object the investigation of these living organisms, animals and plants, with a view to learn how they can live where they do, how they came to be where they are—in short, what are their relations to the world immediately around them and to their fellow organisms—is called *Biology*.

Biology includes all the sciences which treat of animals and plants in any phase of their existence.

This includes plant study—that is, Botany—and animal study—that is, Zoölogy—in the broadest sense of these terms, with the many subdivisions of these subjects. All the divisions of the science of the human body are subdivisions of Biology.

Similarity among Organisms.—These countless forms of life, diverse as they are, have much that is common to all. They live and move by the same laws, and have as their basis the same kind of substance.

They can be thrown into a few groups, the members of which have a very great number of things that are common to all. For example, a single animal well known would lead us to a good general knowledge of the whole animal world.

Thus, a study of the human body and its processes will give a knowledge of the processes of the whole animal kingdom. Muscles, bones, nerves, glands, hearts, lungs, eyes, ears, whatever the tissues and organs, all are essentially of the same composition, and possess the same properties and functions wherever found, whether in the human body or in the body of any of the lower animals.

More than this, the organs of the bodies of all the animals in a single group—say, for example, those of the backboned animals, the vertebrates—are arranged on the very same plan. This plan is carried out in detail to a surprising extent, little

suspected by those who have not made critical comparisons of the bodies of different animals. Thus, a fore leg of a dog, of a cat, of a horse, of a rat, and of a frog, and the wing of a bird, would show very nearly the same muscles, bones, nerves, and blood vessels, arranged nearly in the same way as in the arm of man. A comparison of the other limbs, of the parts of the neck, head, and trunk, would reveal the same similarities of parts and order of arrangement.

The study of the human body, then, may lead to a wider knowledge of the action of living organisms in general. Or, on the other hand, the careful study of some of the lower forms of animals would teach a great amount of what is known of the human body.

The Great Range of the Adaptability of the Human Body.—Of all the forms of the bodies of animals, the human body shows the most wonderful adaptations to the widest range of varying conditions. From this cause, the study of the human body presents us with a most varied and interesting series of problems. These extend from some very simple ones, easy to be understood, to others so difficult that as yet they have baffled the greatest minds in their solution.

This will appear on a little reflection, when we remember how many various kinds of acts it can readily and accurately perform; how it can maintain a nearly constant temperature through many years of changing seasons, of heat and cold, and the ever-varying temperature of a single day; how it can take the materials of food and air and so manage them as to bring them into its various parts, and when there, to transform their elements into its own substance; how it can rechange these substances, and from the energy given off derive the sources of its own energy; how it can further be so affected by light, sounds, pressure, heat, flavors, odors, as to cause ideas to arise from their action; how, again, it may be shaken by emotions or influenced by the will

All these problems have in them a source of the keenest interest to some of the greatest intellects, and surely we may find that which may be of profit to us, even in a brief study of some of the more obvious phenomena of the human body.

Objects to be gained in the Study of the Human Body.—The study of the human body may be made to contribute to the following results:

1. It may be a means of intellectual growth in the attempt to comprehend its facts, to see the true relations of its parts, and to solve its problems.

2. It may be a source of pleasure in seeing more clearly the wonderful adaptations of the body to its conditions, and in tracing its relations.

3. It may give that basis in knowledge which will enable one to understand more clearly the numerous discussions which one must meet in his studies in regard to the activities of living organisms in general, and of the human body and mind in particular.

4. It may give that knowledge which is the surest basis for an intelligent care of the health.

The Study of the Human Body.—*Divisions of the Subject.*—There are many points of view from which we may study the human body.

1. We may examine and describe the structure of the body as a whole, and of each part separately. This science is called *Anatomy.*

2. We may study the properties and uses of each part. This science is called *Physiology.*

3. With facts gained from these preceding sciences, and from the results of experiences, we may form rules for the proper care of the organs of the body. This science is called *Hygiene.*

Anatomy.—To illustrate: If we should take an arm and separate it into its parts—muscle, nerve, bone, blood ves-

sels, and so on—and then carefully determine the position of each, and the relation of each to the others, such work is the study of the anatomy of the arm. Anatomy is the science which treats of structure. If the structure that is considered is only that which can be made out with the scalpel and the naked eye, it is usual to refer to it as *Gross Anatomy*.

But if the microscope is used to further analyze the parts to find their ultimate units, this branch of anatomy is called *Histology*, or the science of tissues.

Physiology.—Now, if, on the other hand, we study what is the action of each muscle, each tendon, the use of each bone; what the use of the blood, or nerve, or what are the properties of each, whether elastic or not, contractile or not—in short, the use or function and the properties of each part, our study is that of *Physiology*.

Hygiene.—To attempt to establish what should be done to keep the parts of the arm in a good working condition—that is, how much the muscle could be worked or how little, what to do in case of a dislocated joint, a torn tendon, a lacerated artery—all such subjects come under the head of hygiene. Hygiene is the science of the care of the body.

To be more accurate, if it is the human body alone that is considered, we should say Human Anatomy and Human Physiology, as the general sciences of anatomy and physiology include the study of the structure and functions of all animals and plants as well as man.

In school work the three sciences—anatomy, physiology, and hygiene—are often for convenience included under the one name, physiology. While this usage has become so general as to prevent breaking up this inaccurate use of the term, we should never lose sight of the real meaning of these separate sciences. Separate as they are in classification, they should never be separated in study.

Directions for Practical Work.

Make systematic observations of at least some of the most conspicuous animals and plants in the immediate neighborhood with this end in view:

To see how they are adapted to the conditions in which they are found. For example: How are the various organs of a robin adapted to the life it leads? In this animal, its beak, its feet, its feathers, its wings, and its tail, may be examined with reference to what each does, and how it does it.

Its food, its habits of flight, of nest building, choice of places for its nest, and many other matters may be observed to find an answer to the question of its adaptations. The hawks, snipes, wrens, and, in fact, any bird in the neighborhood, may be put under study.

Besides these, the insects of various kinds can be used for a like purpose. Trace out some of the adaptations of some insect found in rotting wood, of one found on the bark of trees, or on the leaves of plants. See how their mouths are fitted for the particular kinds of food, their feet for clinging to what they mostly live upon.

The same observations may be continued on fishes, frogs, and crawfishes.

Observe the positions occupied by different kinds of plants. Keep in mind such questions as, What advantage is it to a tree to be tall? What advantage does a vine get from its habits of climbing? What advantage does any plant observed have from its peculiar form? How is it that some plants can survive the winter while others can not? etc.

These are only suggestive directions, but if teacher and pupil will try to carry them out, many others will come from them.

These suggestions can not be finished in a single lesson, but are for continuous work throughout the study of this subject. If continued from day to day, the most valuable ideas in regard to the relations of living things to their surroundings will be obtained, also many facts which form a basis for correct physiological conceptions.

The work outlined above does not need for its aid any book. The names of the parts of the animals observed are not the object of this work and are not necessary to a determination of what office the parts perform in the animal's life. This last can be best learned by the observation of the parts actually in operation.

All such knowledge throws light on the actions of the human body, and is of the utmost importance in elucidating many of its activities.

Review Questions.

1. What does any action of the human body show?

2. Give examples of adaptability shown by the body

3. How is a day's life of the body made up?

4. Give illustrations.

5. What of the number of other organisms?

6. Illustrate by examples.

7. What is the range of form among them?

8. Illustrate by familiar examples.

9. What relation has each to the place in which it lives?

10. Give many examples and show how they illustrate the point.

11. What is Biology?

12. What are some of the divisions of the science of Biology?

13. In what are living beings alike?

14. What relations has the study of the human body to the bodies of the lower animals?

15. Illustrate how they are alike.

16. Give as many evidences as you can of the great range of adaptability of the human body to many conditions.

17. Name the objects which may be gained in the study of the human body, and illustrate each.

18. What are the divisions of the subject?

19. Define each and give illustrations of the definitions.

20. What are the most exact terms to be applied to the study of the human body?

21. What of a common use of the term Physiology?

CHAPTER II.

GENERAL STRUCTURE OF THE BODY.

Materials of the Body—Tissues.—It will greatly help in getting clear notions of the body to learn first something of the nature of the materials of which it is composed. A very large and complex building may be made up of comparatively few materials.

These building materials are usually wood, iron, stone, glass, mortar, brick, paint, and paper. The many rooms, the many parts of each, such as doors, windows, and fixtures, but repeat over and over again in their construction some of the building materials given in the list. In each case the material is selected on account of its peculiar property, for example, glass where transparency is needed, iron for tubes or bars, stone for a broad and firm foundation, and so on.

So in the human body. There is comparatively a small number of different kinds of materials, which are used over and over again in the construction of the various organs. These materials are called the *tissues*.

Examination of the Tissues.—The best way to get a clear conception of the tissues is to examine some part of a freshly killed animal. A joint from the butcher-shop would answer well. A leg of a frog or toad would be better, or a leg of a chicken or rabbit would be admirable. If the skin on the limb of one of these animals is slit down and turned back, it will be found to be tied down to the rest of the limb by white threads, which are somewhat strong. This is *connective tissue*.

In the thick part of the thigh is found a mass of what we

usually call flesh or "lean meat." A closer examination shows this to be composed of a number of bundles which can be separated by gently pressing them apart. These separate pieces are muscles, and will be found to end in strong white cords. These cords run to some point on the surface of the bones, where they are firmly fastened. The colored part of the muscle is *muscular tissue*, the cords being connective tissue. The muscular tissue has the property of contraction; the connective tissue acts as strings, in this case to tie the muscle to the bone.

Next, we may notice the hard, rigid bones, made in part of *osseous tissue*. This tissue is used where rigid bars or hard plates are required. Bones are tied to bones by strings and bands of connective tissue.

Lying among the muscles and sending off numerous branches to them are other white cords, the *nerves—nerve-fiber tissue*. These can be distinguished from the connective tissue by the way they enter the muscles, and from the fact that they are not so strong.

Also packed closely among the muscles, or just under the skin, is the fat, or *fatty tissue*.

If we cut open a joint, we will find the end of each bone covered with a thin cap of smooth, elastic substance, the *cartilage*, or *cartilaginous tissue*, and further examples of connective tissue binding all these parts more or less closely together will be found.

Of the skin, the outer thin layer, together with the feathers and scales on the feet, and the claws in the chicken, and the hairs and claws in the rabbit, are forms of *epidermal tissues*.

List of the Tissues.—Thus, in just one portion of the body the following seven easily distinguished tissues can be readily recognized:

1. connective tissue (inelastic variety).
2. muscular tissue (voluntary variety).

3. osseous tissue.
4. cartilaginous tissue.
5. fatty tissue.
6. epidermal tissue.
7. nerve-fiber tissue.

This includes the majority of those in the human body, and in the chicken and in the rabbit they are like those in man. The remaining tissues which may here be mentioned, and to be described in more detail later, are:

8. nerve-cell tissue.
9. epithelial tissue.
10. other varieties of muscular tissue.
11. other varieties of connective tissue.
12. sense-organ cell tissue.

It may be repeated that the different parts of the body are made up by making use of these materials or *tissues*. For example, the heart is made of muscular, connective, nervous, and fatty tissues (principally); the eye is formed of nervous, sense-organ, muscular, connective, and epidermal tissues, and so on.

Properties of the Tissues.—We can not here study in detail the properties of each tissue, but a brief view will be useful. While each tissue has several properties, each has one or more especially characteristic of it which marks it off from the rest.

Muscular tissue can contract—that is, change its form—and thus produce motion. Osseous tissue is rigid, and can be used in plates, bars, or posts. Nerve-fiber tissue conducts impulses, and thus connects distant parts. Nerve-cell tissue can receive and originate nervous impulses. Connective tissue can be used as strings to tie parts together, the inelastic variety where there must be no giving, the elastic variety where some giving way is necessary, as in the walls of arteries. Epidermal tissues can be formed into plates, hairs, or nails for protecting organs. Epithelial tissue

forms linings of cavities, or even makes secretory cells. Fatty tissue is used as storage of extra food. Sense-organ tissue (sensitive cells in the eye, ear, etc.) is easily affected by light, heat, and the like.

Organs.—The tissues are built up into parts of the body, each of which has a special function to perform. For example, the eye for seeing, the heart for pumping, the stomach for digesting a certain part of the food. Such parts with special functions are called *organs.*

Systems.—Those groups of organs which are more or less united for a common purpose are called *systems.* For example, the heart, the arteries, the veins, and the capillaries, together with the lymphatic vessels, make up the circulatory system.

The Order of the Groups of Parts.—The most comprehensive term in the classification of the parts of the body is, first, the *Body as a whole;* the next in order of terms are the *Systems;* the next are the *Organs*—these may be complex, as the eye, made up of simpler organs; or simple, as a single muscle. The next in order are the *Tissues.* The heart, arteries, veins, and capillary vessels are spoken of as the *circulatory system.* In like manner there are the *osseous system,* the *muscular system,* the *nervous system,* the *digestive system,* the *epidermal system,* and the *connective-tissue system.*

All these comprehensive systems are so connected in one grand comprehensive organism—the body—that they work together to accomplish well its many complex acts.

The Structure of the Tissues.—To the naked eye the tissues appear to be homogeneous substances—that is, without structure or parts. But the microscope has taught us that each of the tissues has a very definite structure, each differing somewhat from the other, but all alike in the essential points.

A thin slice of epidermis properly prepared shows (Fig. 1) that its substance is not the same throughout, but that it is

made up of a number of small bodies whose surfaces touch each other, something like the bricks in a sidewalk or in a house. The gray matter of the brain, nerve-cell tissue, treated in the same way, shows it to be composed of a number of variously shaped bodies more loosely held together. Sections of glands, cartilage, and other tissues also show the substance to be made up of little bodies, more or less closely bound together. These bodies are called *cells*.

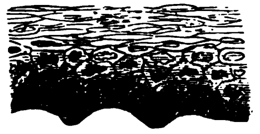


Fig. 1.

SECTION OF THE EPIDERMIS, SHOWING THE CELLS WHICH COMPOSE IT.

Each dark spot is a *nucleus* of a cell; the lines the *walls*.

The Cell.—The *cell* is the *unit* of the tissues. Either its multiplied form joined together in a mass, as in the epidermis, or the substances which they form around themselves, together with themselves, as in the cartilage, or connective tissue, make up the tissues. The cell is the foundation of the tissues. It is the seat of all the activity of the body, whether in motion, sensation, growth, or nutrition. The cells are the individuals, the tissues the communities; the organs are larger, and the systems still larger groups of communities. The whole activity of the body is but the sum of the activities of all the individual cells in the tissues.

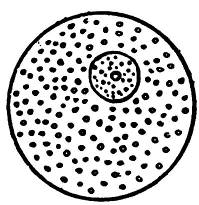


Fig. 2.

A TYPICAL CELL.

The outside ring is the cell wall. The small circle is the nucleus; the smaller one included, the nucleolus. The substance between the nucleus and the wall is protoplasm. The nucleus and protoplasm are living matter.

Since these facts have been learned great attention has been given to the study of the cell. A microscope is necessary for obtaining a clear conception of this unit.

A cell is a small (independent) amount of living matter. Its size, generally microscopic, ranges from the smallest thing yet seen with the highest powers of the microscope up to those plainly visible to the naked eye.

The great majority of the cells in the human body, however, are between $\frac{1}{3000}$ and $\frac{1}{500}$ of an inch in diameter. The cell often forms around itself a layer firmer than its contents, called the *cell-wall.* The essential part of the contents of a living cell is always a substance called *protoplasm,* in which is inclosed a small amount of substance of a slightly different appearance from the protoplasm, called the *nucleus.* These parts are shown in Fig. 2, a drawing of a typical cell. The protoplasm and nucleus are regarded as *living matter.* These parts of the cells are all of the body that is really alive. It is the action of this living matter, protoplasm, that we see in the activities of the body.

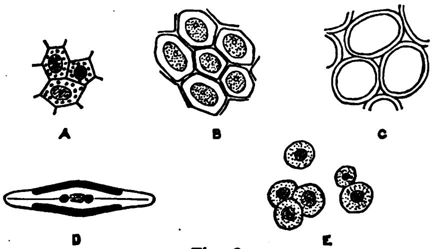


Fig. 3.

CELLS FROM COMMON PLANTS, MAGNIFIED. DRAWN FROM NATURE, EXCEPT *A*, BY E. HUGHES.

A, growing cells in a young stem; *B*, cells in a thin section of young root of onion; *C*, cells from a thin section of May Apple stem; *D*, a diatom, a one-celled plant found in ponds; *E*, a group of one-celled plants from the green coating formed on the north side of a locust-tree.

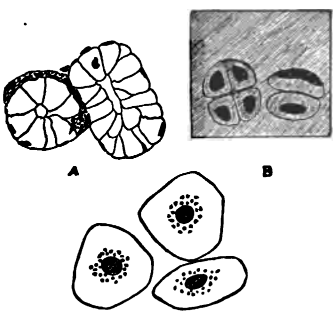


Fig. 4.

CELLS FROM ANIMAL TISSUES, MAGNIFIED.

A, a group of cells from a salivary gland; *B*, cartilage cells; *C*, epithelial cells from the lining of the mouth. Drawn from the objects by E. H.

The cell is not the unit of the tissues in the human body alone, but it is also the unit throughout the whole animal and plant kingdoms. A thin slice of wood, bark, leaf, or part of a flower, or of a seed, shows it to be made up wholly of many little cells more or less closely cemented together.

In plants they are like so many little boxes packed closely together. In Fig. 3 there are represented cells from some of the most common plants. Fig. 4 shows the appearance of certain tissues of the body.

Shapes of Cells.—The shapes of the cells will depend in both plant and animal somewhat on the way they are crowded together, or on the method of their growth. In the large plant or animal the cells are no larger than those in the small one. The difference in sizes of animals and plants is due to the difference in the number of the cells which build them up. The higher plants and animals, including man, consist of countless millions of cells, while the very lowest plants, as well as the lowest animals, *consist of a single cell* (Figs. 3 and 5).

The Study of a Single-Celled Animal.—The animals or plants of only one cell offer more excellent opportunities for seeing how living matter acts than do the cells of the tissues. A drop of water from the scum or sediment of a pond, or from a vessel of water in which some vegetable or animal substance is decaying, will generally show under moderate powers of the microscope great numbers of these one-celled animals or plants, darting rapidly or creeping slowly about.

By some care they can be kept alive under the eye for some time and all their processes observed. In this case we may study our simple unit—the cell—in its activity, and seeing what the independent cell can do alone, we may understand better what a collection of units in the tissues can do, acting together.

A One-Celled Animal as a Physiological Unit.—Among many one-celled animals, one tolerably common is well suited to our purpose. It is called the Amœba (Fig. 5). It is a small mass of protoplasm with a nucleus. It is a single cell, but without a cell-wall. It has the power of slowly changing its form, which it does by pushing out first one side of its body, then another. It can also pull all these

projections in and take another shape. While it has no muscles, yet its whole body can contract. When it comes in contact with what may injure it, it draws away. When an object may serve as food, it pushes itself over the small object and holds it within itself until it is digested. If part of this food-object is indigestible, it pulls itself away from it and leaves it behind. If it is jarred or struck, or an electric shock sent through it, it shows that it feels it. When it attains a certain size, it gradually separates into two parts, which move away, each to lead an independent existence. It takes up oxygen and throws off carbon dioxide (*see Respiration*).

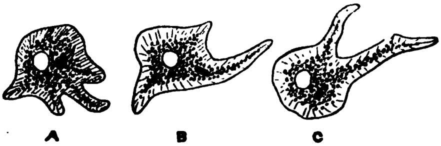


Fig. 5.

AN AMŒBA. Drawn by E. H.

A, *B*, and *C*, three successive forms assumed by the animal in a few minutes. The specimen obtained in a ditch near Greencastle, Ind.

Now, all these things are just what the large body of the higher animal does, even the human body. This little animal, with neither tissue nor organs, performs what the higher animal body does by means of organs and tissues. To be sure, its motion is not so rapid nor precise, its powers in any direction not so marked, yet its processes are motion, feeling, digestion, respiration, excretion, secretion, etc., the processes of all animals, even of the highest.

What is the difference? A few more steps in the series between these two extremes will help us grasp the meaning of the difference.

A Series of Animals connecting the Simplest with the Highest.—In our ponds there lives another little animal, just large enough to be seen with the naked eye—the Fresh-water Hydra (Fig. 6). This little animal has a sac-shaped body, from around the mouth of which extend six or eight arms. It can catch little animals with these arms, pull them

into its mouth, and digest them. It can move about, and perform many quite complex actions. Its actions are much more prompt, vigorous, and complex than those of the amœba, yet a careful study of its structure shows it to have no true tissues, no muscles, nerves, brain, glands, eyes, ears, or the like. It consists of two layers of cells, in which the cells are in contact with each other (Fig. 7). When one cell is touched it communicates this effect to its neighbor, and this to the next, and so on until all have felt it. Then, if it moves, it does so by almost all the cells contracting. Almost, if not all, the cells can digest, and all can carry on respiration, secretion, and other physiological processes.

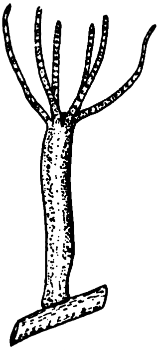


Fig. 6.

A FRESH-WATER HYDRA, FROM A SPRING NEAR GREENCASTLE, IND. Drawn from nature (magnified) by E. H.

Fig. 7.

IDEAL SECTION OF A HYDRA, TO SHOW THE TWO LAYERS OF CELLS MAKING UP ITS BODY. E. H.

Now, physiologists have been able to fill up the series with examples of animals which show more and more perfectly developed tissues, until we arrive at man and the highest animals, which have the perfect tissues enumerated above. The contemplation of such a series led a great physiologist, Milne-Edwards, to speak of the tissues of the higher animals as showing a conformation to the principle of *Division of Labor.*

Division of Labor.—Communities of men are organized on this principle, and by this means a number of men working together can accomplish vastly more than the same number working separately. For example, in one community one set of men plant and gather in the crops; another set grind the grain; another make it into bread; another make cloth; another make clothes; another make leather; another make

shoes; and some act as physicians; some lawyers, etc. The whole work of the community is so greatly divided up that it would take a whole book to give a list of the various processes performed. Now, every person receives great advantage from the action of this principle. Each learning to do well one set of actions, can turn out perfect products of his skilled labor, and by a system of exchange can come to possess the products of the skilled labor of others, and thus have all the conveniences and luxuries of civilized life. If each should be compelled to work alone and not receive any advantages from his neighbor's work, he could accomplish very little, and that of an inferior grade. In this way the human race would have made but little progress, and civilization, with all that it means, would be impossible.

Physiological Division of Labor.—In the human body the various groups of cells called tissues have divided among them the various physiological processes—muscle cells for contraction; gland cells for secreting digestive liquids; nerve-fiber cells for the conducting of impulses; sense-organ cells of different kinds to be affected by light, sound, etc. These groups, attending to their functions either alone or jointly, allow the whole group of communities to perform in a wonderfully better way these processes than could all the cells working separately, as in the amœba. This is known as *Physiological Division of Labor.* The reader will find profit in extending this comparison to a much greater limit than given here. A clear comprehension of the relation of the human body to the single-celled organisms is the key to a correct view of the processes in the higher forms.

Life of the Cells in the Tissues.—While the individual cells thus grouped into tissues have the characteristic activities just described as peculiar to the group, still each cell retains many forms of activity common to all living cells. Each cell still takes in oxygen and throws off carbon dioxide; each cell requires food as much as if it lived alone. They all

have at least at some time in their life the power to increase in size and reproduce themselves by dividing, generally into two parts, just as the amœba or any other one-celled animal or plant may do.

This is the way the tissues grow—that is, by the growth and multiplication of the individual cells, which push on each other and thus extend the whole tissue into a new and larger size; or where the tissues are torn or otherwise injured, replace the lost parts and knit the whole together again.

Organisms constructed on Definite Plans.—As in the construction of a house, of a bridge, of a ship, or of an engine, there is a plan by which the parts are grouped together, so in all organisms the structure always follows some definite plan. Indeed, a plan is essential in the conception of the term organism, as it is essential to the existence of the organism itself. The plan of each limits its operations.

While it would require wide observation and long study to comprehend the full meaning of the plan of any organism, yet even a cursory view of the main features of the plans on which animals are constructed will help in gaining a knowledge of the human body.

Plan of the Body.—The human body is constructed on the plan of the body of all vertebrate animals. The vertebrates are the fishes, reptiles, batrachians (frogs and salamanders), birds, and mammals. The plan consists of a *central axial portion* formed of the *head* and *trunk*, connected in man and in most vertebrates by the *neck*. This last is absent in most fishes, the head being continuous with the body. Certain portions of the trunk are extended into two pairs of appendages, the arms and legs. These are rudimentary or absent, in part or altogether, in some vertebrates. But when present, the appendages are always in the same relative positions and formed on the same plans. Only in man are the first pair used exclusively as arms.

The axial portion—the head, neck, and trunk—consists of a sort of double tube; the outside integument, or skin, being one portion, and the lining of the alimentary canal the other. Between the surfaces of these tubes lie all the organs of the body, arranged in a definite order in relation to these.

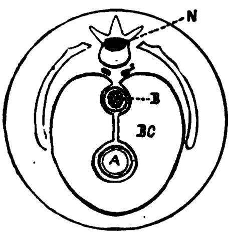


Fig. 8.

SHOWING PLAN OF CROSS-SECTION OF A VERTEBRATE.

Outside ring, skin of body; *A*, alimentary canal; *B*, axial blood tube; *N*, axial nerve cord; *BC*, body cavity (thoracic or abdominal). E. H.

Imbedded in the dorsal surface of the trunk, midway between the walls of the two tubes mentioned, is a rigid axis. In man and most other vertebrates this consists of a series of bones closely locked together. This is called the *axial skeleton*, consisting of a skull and a spinal column.

Inclosed in this axial skeleton is the brain and the spinal cord, which is the *axial portion* of the *nervous system.*

In the ventral side of the trunk of man and other vertebrates there is always present a cavity, known in Comparative Anatomy as the *body cavity.* In many vertebrates, as in the frogs and fishes, it consists of one room, containing the lungs, heart, liver, stomach, intestines, etc. In the class to which man belongs—*the mammals*—it is divided into two rooms by a partition called the diaphragm; the upper (anterior) room is the *thoracic cavity*, the lower (posterior) the *abdominal cavity.* Suspended in one are the lungs and heart; in the other, the main organs of digestion.

Lying between this body cavity and the axial skeleton is the main axis of the circulatory system—the aorta.

Just ventral to the axial skeleton, and back of the axial blood tube, lies the main axis of the sympathetic nervous system (Fig. 8).

Between the outer skin and the walls of the body cavity lies the mass of voluntary muscles of the trunk, and im-

bedded among them the bones, nerves, and blood vessels. This order of arrangement is preserved throughout the vertebrate group. Indeed, such animals are grouped together because they have the same plan.

The plan of Worms and Insects (Fig. 9) agrees in having head and trunk and appendages; also, in having the parts of the trunk between the walls of the double tube, and in possessing a body cavity; but differs materially in the absence of an axial skeleton, and in having the axial portion of the nervous system on *the ventral side* of the alimentary canal and the body cavity.

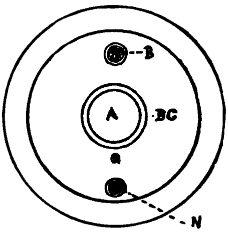


Fig. 9.

SHOWING PLAN OF CROSS-SECTION OF INSECTS AND WORMS. E. H.

A, alimentary canal; *B*, axial blood tube; *BC*, body cavity; *N*, axial nerve cord.

In such animals as Snails and River Mussels (Fig. 10), while there is the double tube, the body cavity, and an axial blood tube, there is no axial skeleton or axial nervous system, either ventral or dorsal. The nervous system is scattered through the body.

In the Fresh-water Hydra (Fig. 7), the double-tube arrangement is not present, the digestive cavity being a depression in the body. The body cavity is not evident. There is no nervous, muscular, or blood system.

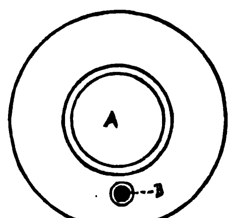


Fig. 10.

PLAN OF CROSS-SECTION OF RIVER MUSSEL. E. H.

A, alimentary canal; *B*, axial blood tube.

These plans do not exhaust the list, but serve to show how the general plan of an animal may vary. Still, the general plans are not very numerous, and allow a classification of immense numbers of forms into a few groups.

Directions for Practical Work.

To show the Tissues.—As was stated in the text, the leg of a chicken answers excellently for the purpose of demonstrating the tissues. The whole leg, foot and all, should be used. Make an incision lengthwise with the leg. The skin is easily separated from the parts beneath, and should be turned back and not entirely removed. This immediately exposes the parts in a compact mass.

To show of what the mass of flesh is composed, separate the parts completely. This can be done by pressing them apart with some blunt instrument, like the handle of a scalpel, or a sharpened pencil, as the small amount of connective tissue holding them together may be torn easily. The blade of a knife may be used, but with care, to separate the most resisting points, or it will cut into the parts and destroy the dissection. Do not cut away the muscles, tendons, or nerves. By this means all the muscles of the leg can be separated and the tendons traced in their attachments to the bones. The nerves and blood vessels and the fat may also be seen. The muscles can be pulled, and thus show how the limb would be moved by each, how the tendons act, etc.

If the specimen is to be kept a day or so, the skin must be replaced on it to keep it moist.

The feathers may now be examined and the mode of their insertion. Also the insertion of the sort of scales on the legs and the claws. This demonstration is very easily made and will abundantly repay the trouble it takes. By now laying open one of the joints, cartilage may be observed, and by cutting through the bone its appearance may be studied.

If a chicken is not available, any other small animal, as a squirrel, rat, or bird of some kind, or a frog or toad may be used. Even a soup-bone from the butcher shop would be better than nothing.

To study Cells.—For this purpose a compound microscope is necessary. To show the form of plant cells, make thin slices of any part of the plant and mount the slice in water and examine.

The following are good objects: Pith of elder, cork, potato, a young growing stem. For a single-celled plant take the green coating which is often found on the north side of trees. Scrape off a little and mount it in water, and large numbers of round green cells may be seen. Sediment from a ditch or pond will show great numbers of one-celled plants. One-celled animals may be found also in ditch or pond water. Great numbers of Paramecia, one-celled animals, may be obtained by allowing a piece of vegetable matter—apple-paring, for example—to stand in a glass of water in a warm room until it begins to decay. The scum around the decaying apple-paring will abound in the little animals. Their motions,

feeding, and divisions for reproduction may be observed. Cells in the tissues of animals are harder to prepare. The easiest to obtain is a slice of cartilage made with a razor and mounted in water. A bone with the fresh cartilage can be obtained at the butcher shop. The teacher can easily learn to prepare the more difficult tissues, or can purchase prepared specimens.

The Hydra is to be looked for on floating sticks or plants in ditches or ponds. Sometimes they are found in great numbers; at other times they are scarce in the same locality. Amœbæ are found in similar situations, and, although common, can not always be obtained.

Review Questions.

1. What are the common materials used in building houses?

2. For what is each used and why is it selected for that particular purpose?

3. What are tissues?

4. Have you seen animal tissues? Describe the appearance of each tissue that you have recognized.

5. What properties are characteristic of each?

6. How do these compare with the building materials of the house?

7. What is connective tissue used for in the body? Muscular tissue? Fatty tissue? Nerve-cell tissue? Nerve-fiber tissue? Epidermal tissue? Epithelial tissue? Sense-organ cell tissue? Cartilaginous tissue?

8. Give a number of places where each is made use of.

9. What is an organ?

10. Of what is it composed? Illustrate.

11. What is a system? Illustrate.

12. Give the relations of tissue, system, organ, and body to each other.

13. Describe the structure of a tissue.

14. Illustrate with drawings.

15. What is the unit of the body?

16. What is a cell?

17. Explain why the cell is considered the unit of the body.

18. What does Fig. 1 show?

19. What are the dots and what the lines in the figure?

20. How are the tissues of glands and cartilage made up?

21. What is the relation of the cell to the tissues?

22. On what does the activity of the cell depend?

23. Of what importance is the cell?

24. Define a cell, and describe a typical one.

25. Explain Fig. 2.

26. How large are cells?

27. What is protoplasm?

28. What is the active part of the cell?

29. In what else beside the human tissues is the cell the unit?

30. How are plants made up?

31. Describe each part of Fig. 3.

32. Explain Fig. 4.

33. On what do the shapes of the cells depend?

34. What relations do the size of the cells have in different animals and plants?

35. Where may single-celled animals be found? Have you ever seen any such?

36. What advantage does their study offer?

37. Describe the amœba. Where found?

38. What can it do? How does it perform each action? Has it tissues or organs?

39. How does it reproduce itself?

40. How do its actions compare with those of the human body?

41. Describe the fresh-water hydra. Of what actions is it capable?

42. What is the structure of its body?

43. How does it move, feel, digest, etc.?

44. What does Fig. 7 show?

45. What would a series of animals from the lowest to the highest show in regard to tissues?

46. What is the principle of the division of labor? Illustrate from your own community.

47. What advantages does the community derive from it? Illustrate.

48. How is the principle made use of in the work of the body?

49. What advantages are gained by it?

50. What of the individual life of each cell in the tissues?

51. Compare now the amœba to the human body, as regards both structure and actions.

52. How do tissues grow?

53. What of the plans shown by the structure of the organisms?

54. Describe in detail the plan of the vertebrates.

55. Reproduce Fig. 8, and explain it.

56. Describe the plan of the bodies of insects and worms.

57. Reproduce and explain Fig. 9.

58. Reproduce and explain Fig. 10.

59. What is the plan of the body of a fresh-water hydra?

CHAPTER III.

THE SKELETON.

General View of the Skeleton.—One of the distinguishing characteristics of animals is their power to move from place to place. Most of them accomplish this by pushing against something with a part of their bodies. Those that swim, push against the water; those that fly, against the air; and those that walk, run, jump, or climb, push against some solid body. In all these cases the force is exerted by muscles, which act on more or less solid levers. The levers are applied at their outer ends, by the proper organs, to either the air, water, or the solid ground, and at their inner ends to the main body of the animal. This calls for firm, solid parts in the main body or trunk. All these solid parts together are known as *the skeleton.*

The Two Kinds of Skeletons.—These solid parts in such animals are supplied in two ways:

In one group, such as craw-fishes, insects, crabs, and lobsters, the outer portion of the body is made into a hard crust, with joints in the limbs and generally in the body. Inside of these hard coverings are the muscles, which are attached to places in the limbs and to the main trunk, so that when the muscles pull, the limb will be bent or straightened, and thus push the body along.

In the other group, including all the *vertebrates*, or animals with backbones—that is, fishes, frogs, reptiles, birds, and mammals—the firm, solid portions which are to act as levers to push the body along, or to make the body firm so that it may receive the effect of those pushes, are buried

deep in the limbs or in the trunk, and are covered by the muscles, which are attached to the outside of them.

Thus, while we may see these two kinds of skeletons formed in these different ways among animals, yet the main purpose is the same in both—that is, to act as a system of levers by which the force from the contraction of muscles may be applied to accomplish the various motions of their bodies, not of locomotion only, but of all the motions of the body, except those of the heart, blood vessels, and alimentary canal.

In those animals which have their skeleton external, it is only the skin that is very much hardened. This is called the *exoskeleton.* In vertebrates the skeleton is a development of a special class of tissues for this purpose, *true bone*, *cartilage*, and *connective tissue.* This is called the *endoskeleton.*

Fig. 11.

THE SKELETON.

Plan of the Skeleton.—In the study of the hu-

man skeleton we may be greatly aided by a comparative study of the skeletons of other vertebrates—say of a dog, cat, chicken, or frog. In fact, any skeleton will help us. We will find all vertebrate skeletons built upon the same plan, and in the higher vertebrates, as in a cat or dog, almost the same bones with nearly the same shape.

The plan consists of:

First.—A fairly rigid *bony axis*, composed of the *spinal column* and the *bones* of the *head*. To a part of the spinal column are attached the *ribs*, the main use of which is to serve as the framework of a breathing apparatus.

Second.—Attached to the bony axis are the two portions of the *appendicular skeleton*, the bones of the limbs and the bony arches by which they are attached to the trunk.

The upper arch is the *pectoral girdle;* the lower, the *pelvic girdle.*

The Spinal Column.—The Spinal Column consists of twenty-six pieces: twenty-four *vertebræ*, the *sacrum*, and the *coccyx*. The vertebræ are repetitions of a single form, with small differences in the development of its parts to answer to the requirements of the different parts of the column. The sacrum is really composed of five vertebræ grown together, and the coccyx of four

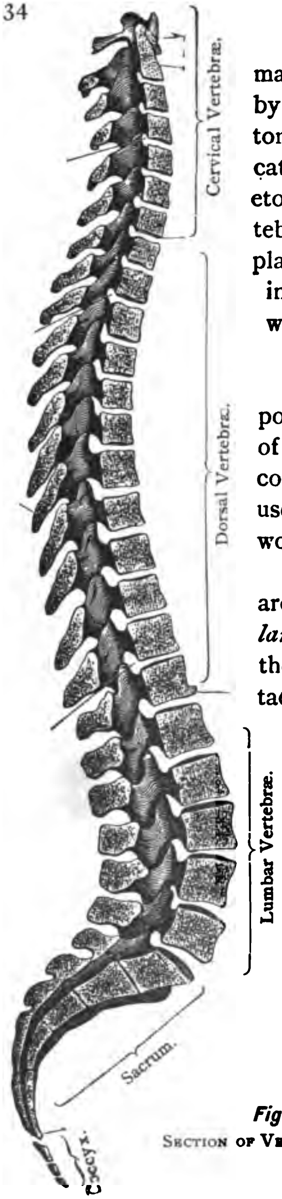


Fig. 12.
SECTION OF VERTEBRAL COLUMN.

rudimentary vertebræ grown together. In some animals the sacrum and coccyx remain in separate vertebræ. The vertebræ are known in three groups:

Seven Cervical vertebræ—those in the neck.

Twelve Dorsal vertebræ—those to which the ribs are attached, known also as *Thoracic vertebræ.*

Five Lumbar vertebræ—those in the loins (see Fig. 12).

A Vertebra.—Any one of the vertebræ might be chosen for the study of the plan. Let us select a dorsal vertebra (Fig. 13). It consists of a large central part, the *body* or *centrum*, which bears seven projections or processes—one long one extending backward and downward, the *spinous process;* one on each side, the *transverse processes;* and two forward and two backward processes to join corresponding processes on the vertebra before and the one behind, by which a slightly movable joint between each two vertebræ is formed. The spinous process may be considered to stand on two roots, which on joining the centrum inclose the opening through which the spinal cord extends as far as the second lumbar vertebra, while a bunch of nerves passes through the remainder of the canal.

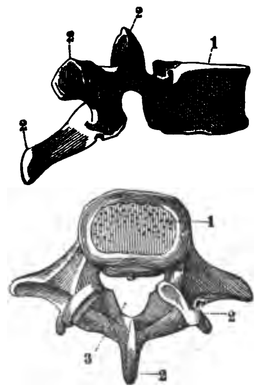


Fig. 13.

A DORSAL VERTEBRA, SHOWN IN TWO POSITIONS.

It would be very interesting and profitable to compare the various vertebræ with each other, and make out on each the body, the seven processes, and the foramen. This can be done with the vertebræ of the lower animals as well as with the human vertebræ.

Atlas and Axis.—The vertebra which differs most from the one described as typical is the first cervical vertebra, called the Atlas. It is fitted to support the skull by means

of its articulation with the occipital bone above. It articulates with the second cervical vertebra below, called the axis, which bears the *odontoid process*, around which it can turn as on a pivot. This arrangement permits much freer motion than is allowed between any of the other vertebræ. By this means the turning of the head through a large part of a circle, and the nodding of the head on any part of that circle, is possible.

Articulation of Other Vertebræ.—Between the bodies of the vertebræ are pads of an elastic tissue (fibro-cartilage) which, while they bind them firmly together, also allow considerable motion. They are quite elastic, thus acting as springs in getting rid of the effect of jars to the body, especially to the head, in walking, running, or jumping.

The processes are for the attachment of ligaments, which bind firmly one vertebra with its neighbors and with the ribs. They are also used for the attachment of very many muscles, some of which move the limbs, some the head, and some the ribs.

The canal which is formed by bringing into line (see Fig. 12) the openings in the vertebræ is the *spinal canal*, which is a passage for the spinal cord, well protected by masses of bone and tough ligaments and masses of muscle.

The separate vertebræ, fitted together so nicely and bound together so strongly, make the spinal column a firm mass, having several uses, the main ones being as the principal axis of support for the rest of the body, and for the attachment of the great muscles which produce the motions of the trunk, head, and limbs.

The Ribs.—Attached to the twelve dorsal vertebræ are the twelve pairs of ribs. These curve downward and forward, the first seven joining by elastic rods of cartilage to the breast-bone, *the sternum*, the cartilages of the next three not reaching to the sternum, but joining to the cartilages of those above. The front extremities of the last two are free.

Hyoid Bone.—The *hyoid* bone is a small U-shaped bone, which can be felt just beneath the skin above that part of the larynx called "Adam's Apple." The convex part of the bone is forward, its points extending backward. Many muscles are attached to it, the largest of which is in the root of the tongue.

The Skull.—The anterior end of the axial skeleton is the skull, which is divided into a *cranial* and a *facial portion.*

Fig. 14.

THE SKULL.

The *cranium* consists of eight bones, which form the walls of a room in which the brain is lodged.

The central part of the floor of this room is the *sphenoid* bone, a very irregularly shaped bone, whose edges touch each of the other bones in the cranium.

There rises up from it behind, the *occipital bone.* This is perforated by a large opening for the passage of the spinal cord, called the foramen magnum.

From each side rises a *temporal* bone. This has imbedded in it the channels of the ear. The external auditory canal is very conspicuous in it.

Rising above each temporal bone, and joining each other along the median line, are the *parietals.* These join the occipital behind and the frontal in front, and with it make a dome-shaped roof.

The *frontal* also makes the front wall and a large part of the floor of the room.

Also, in the floor in front is the *ethmoid bone*, which is perforated for the passage of the many filaments of the olfactory nerves. The ethmoid extends downward from the cranium and joins many bones of the face.

The other bones of the floor of the cranium are perforated for the passage of blood vessels and nerves to and from the brain.

The *facial portion* consists of fourteen bones: those bearing the teeth, one *lower maxillary*, or mandible, and two *superior maxillaries*. Above these, and prominent in the cheeks just under the eyes, are the *malar bones*. The two *nasals* form the bridge of the nose, the *vomer* helps form the partition between the nostrils. The two *lower turbinated bones* form rolled shelves projecting into the nasal passages. The two *palate* bones are just back of the superior maxillaries, but so imbedded among the other bones that only the small portion which helps form the hard palate is easily seen. The two *lachrymals* are each near the inner angle of the orbit of the eye, and each is perforated by a tear duct.

Fig. 15.

SHOULDER BLADE.

Scapula.

In the cavity of each middle ear is the series of ear bones, the *malleus*, *incus*, and *stapes*.

The Appendicular Skeleton.—This term is applied to the bones of the arms and legs and the arches of bone which serve to attach them to the trunk.

The *shoulder girdle* is the upper arch, and consists of the *scapula* and *clavicle*. The scapula—the shoulder-blade—is a flat, triangular bone on the back of the shoulder. It has a

shallow cup at one corner for the articulation of the head of the humerus. The clavicle—the collar-bone—can easily be traced under the skin at the base of the neck. It extends from the upper end of the sternum to the scapula, and serves to hold the shoulder joint back from the chest.

The bones of the upper limb are: The large bone of the arm, the *humerus* (Fig. 16), the upper end having a rounded head to articulate with the socket on the scapula, the lower end with a grooved surface to articulate with the bones of the fore-arm. The bones of the fore-arm are the *radius* and *ulna*. The radius is broad at the wrist and forms the articulating surface for the hand, which it carries. The ulna has its large end at the elbow. It forms with the humerus that part of the elbow joint which works like a hinge. When the whole arm is straightened the humerus and ulna form a rigid bar, by a projection on the ulna locking in a depression on the humerus. The radius is turned over the ulna in the act of turning over the hand. When the palm of the hand is turned upward, the radius (on the thumb side) is parallel with the ulna. When the palm is turned downward, the radius crosses the ulna.

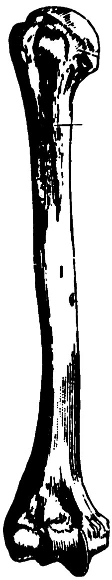


Fig. 16.

HUMERUS.

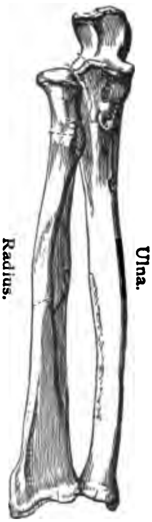


Fig. 17.

BONES OF FORE ARM.

This power of rotating the radius and thus turning the hand is also possessed by the monkeys, very slightly by cats, but not by dogs, while in horses and cows the radius and ulna are fused together into one bone.

The bones of the wrist are the *carpals*. They are small in

size and irregular in shape, and are arranged in two rows of four in each row, and are bound firmly together. The five *metacarpals* come next, supporting the palm of the hand and acting as the base of the thumb and fingers. The skeleton of the fingers consists of the *phalanges* (singular, phalanx), two in the thumb and three in each finger. The first metacarpal, carrying the thumb, has a much freer motion than the others, thus allowing the thumb to be brought opposite to any one of the fingers. This greatly increases the usefulness of the hand as a prehensile organ.

The Pelvic Girdle consists of one bone on each side, the *os innominatum* (the hip-bone). This bone is braced against the sacrum behind, and its fellow in front, and presents on the outer surface a deep cup for the reception of the head of the femur. This cup is called the *acetabulum*. This arch of bone is made very firm, since in supporting the weight of the trunk or in carrying any additional weight, and in running, walking, or jumping, great force is applied to it through the femur.

The bones of the lower limb correspond mainly to those of the upper limb. In the thigh is the large *femur*, joining with the hip-bones above and with the *tibia* at the knee joint. Below the knee is the large *tibia*, and parallel with it, the slender *fibula*. In the ankle are the *tarsals*, seven in number; the one articulating with the tibia is the *astragalus*, the large one in the heel, the *calcaneum* (Fig. 18). The other five are small. In the arch

Fig. 18.

BONES OF THE FOOT—SECTIONAL VIEW.

of the foot are the five *metatarsals*, which support the toes with fourteen phalanges. The *patella* is a bony disk imbedded in the large ligament which lies over the knee. It is called the knee-cap. Sometimes small bones are found imbedded in some of the ligaments on the under side of the foot, which are called the *sesamoid bones*.

Comparison of the Human Skeleton with the Skeletons of other Animals.—In comparing the human skeleton with those of such animals as the horse, the cow, and the dog, such differences are seen as are demanded by the different methods of locomotion. The spinal column of man is narrower toward the head and broader toward the pelvis. The pelvic girdle is broader. The bones of the face are reduced in size, while those of the cranium are greatly developed to accommodate a greatly developed brain. The whole head is balanced on the top of the spinal column instead of being suspended from its extremity. The arms are held back by the clavicles. The upper limbs are otherwise modified for prehensile organs. The lower limbs are brought to support the body in a perpendicular position. The foot also shows its adaptation to the peculiar positions of the human body in locomotion.

Directions for Practical Work.

If a human skeleton or parts of it can be obtained, this should be done. Sometimes a little trouble may procure a loan of parts of the skeleton from a physician or a neighboring school.

But no school need be without a good skeleton of a dog, or of a cat, or of a rabbit, any one of which would well illustrate the subject, as the bones are very much like those of the human skeleton. The greatest differences are found in those of the skull. Often these may be found in the fields or woods already prepared. But if not, a skeleton may be prepared with some little trouble.

Two or three of the class might undertake this, the bones being kept for succeeding classes.

Clean off as much of the flesh as can be readily done with a knife. Separate the parts and boil them in water, containing a few lumps of hard soap and a small amount of saltpeter. This will loosen the tendons and ligaments so that they can be scraped off. The process will also remove the fat of the marrow. After they have been thoroughly cleansed they may be bleached, if desired, by leaving them exposed to the rain and sunshine.

Members of the class may from the fields and woods add many separate bones of different animals, which can with little trouble be made sufficiently clean to work with. Such means of obtaining correct ideas of bones are superior to descriptions and charts.

Review Questions.

1. How do animals move?
2. What is the skeleton and its use?
3. What is the difference between the skeleton of a crawfish and that of a dog?
4. What are the two kinds of skeletons?
5. Give examples.
6. Of what is each kind composed?
7. What of the comparative study of skeletons?
8. What is the plan of the human skeleton?
9. Describe the spinal column.
10. Give the groups of the vertebræ.
11. Describe a vertebra.
12. Describe the atlas.
13. How does it articulate with the skull? With the axis?
14. What motions does this arrangement permit?
15. How are the other vertebræ joined together?
16. What advantages are thus gained?
17. What are the uses of the processes?
18. How is the spinal canal formed?
19. What are the uses of the spinal column as a whole?
20. Describe the position of the ribs.

21. How are they attached?

22. Give the position and description of the hyoid bone.

23. Describe the skull.

24. Name, and give the position of, each of the bones of the cranium.

25. Where is the external auditory canal?

26. Where is the foramen magnum?

27. Point out these bones in the figure of the skull.

28. Locate each of the bones of the face.

29. What is meant by the Appendicular Skeleton?

30. Describe the shoulder girdle.

31. Locate the humerus, and give its articulations.

32. What are the bones of the fore-arm, and how are they arranged?

33. How is the motion of turning the hand over accomplished?

34. Where are the carpals? Give arrangement.

35. Locate the metacarpals.

36. What are the phalanges, and how are they distributed?

37. Give the action of the fingers and the thumb.

38. Draw a diagram showing the relations of the bones of the upper extremities.

39. Describe the pelvic girdle.

40. Describe the femur and its articulations.

41. Name and locate the bones of the lower portion of the leg.

42. What is the use of the pectoral girdle?

43. Describe the tarsus.

44. Where is the astragalus and calcaneum?

45. Locate the patella.

46. What are the sesamoid bones?

47. Give the main differences between the human skeleton and those of the lower animals.

TABLE OF THE BONES.

I. Axial Skeleton.

- *A.* Skull, 28.
  - 1. Cranium, 8.
    - *a.* Frontal, forehead, ... 1
    - *b.* Parietal, ... 2
    - *c.* Temporals, temples, ... 2
    - *d.* Occipital, ... 1
    - *e.* Sphenoid, ... 1
    - *f.* Ethmoid, ... 1
  - 2. Face, 14.
    - *a.* Inferior Maxillary, lower jaw, . . 1
    - *b.* Superior Maxillaries, upper jaw, . 2
    - *c.* Palatine, palate, ... 2
    - *d.* Nasal Bones, bridge of nose, . . 2
    - *e.* Vomer, ... 1
    - *f.* Inferior Turbinated, ... 2
    - *g.* Lachrymals, ... 2
    - *h.* Malars, cheek bones, ... 2
  - 3. Bones of the Ear, 6.
    - *a.* Malleus, ... 2
    - *b.* Incus, ... 2
    - *c.* Stapes, ... 2
- *B.* Spinal Column, 26.
  - 1. Cervical, or neck vertebræ, . . . 7
  - 2. Dorsal, or thoracic vertebræ, . . . 12
  - 3. Lumbar vertebræ, ... 5
  - 4. Sacrum, ... 1
  - 5. Coccyx, ... 1
- *C.* Thorax, 25.
  - 1. Ribs, ... 24
  - 2. Sternum, ... 1
- *D.* Hyoid, 1, ... 1

II. Appendicular Skeleton.

- *A.* Shoulder Girdle, 4.
  - 1. Clavicle, collar-bone, ... 2
  - 2. Scapula, shoulder-blade, ... 2

B. Upper Extremities, 60.

1. Humerus,	2
2. Radius,	2
3. Ulna,	2
4. Carpals, wrist bones,	16
5. Metacarpals,	10
6. Phalanges,	28

C. Pelvic Girdle, 2.

1. Os innominatum,	2

D. Lower Extremities, 60.

1. Femur, thigh bone,	2
2. Tibia,	2
3. Fibula,	2
4. Patella, knee-cap,	2
5. Tarsals, ankle bones,	14
6. Metatarsals, bones of the instep,	10
7. Phalanges, bones of the toes,	28

CHAPTER IV.

STRUCTURE OF BONE.—ARTICULATIONS.

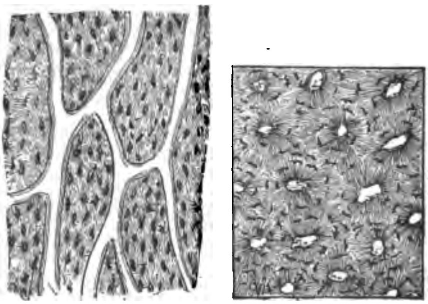
Structure of Bone.—A bone as seen in a prepared human skeleton, or one of some of the lower animals picked up in the fields, shows us only the hard calcified portion of the bone. A living bone, or one in a fresh condition—the femur, for example—has the two extremities capped with a layer of dense, white elastic tissue, called *cartilage*, and a sheath of connective tissue, the *periosteum*, inclosing the shaft. Beneath these coverings lies the calcified portion. The shaft of the bone is hollow, the space being filled with *yellow marrow*. The walls of the shaft are thick and of great density. At the extremities of the bones only the outer layer is dense, the interior being occupied with a loose net-work of bone, something like a sponge. The spaces are filled with a substance called *red marrow*. Distributed through the periosteum and penetrating the hard substance of the bone are great numbers of blood vessels. Even in the densest part of the shaft every small portion contains a complete net-work of small blood vessels, called the *Haversian canals*. (See Fig. 18.)

Uses of the Parts.—The whole bone, as the femur, is used as a lever, and also as the fulcrum of another lever at the knee. The cartilage caps present as smooth surfaces as possible for movement in the joints. The periosteum furnishes a means for the attachment of tendons of muscles and of the ligaments. It also supports the blood vessels which supply nutrition, and the nerves which control the nutrition of the parts beneath. The hard part of the bones, the calcareous substance, is to make the bone rigid. This is distributed through the bone in an excellent way to give, with a small amount of material, great strength and considerable surface, especially at the ex-

tremities, for the formation of joints and surfaces for attachment of the tendons and ligaments.

The yellow marrow is probably like fat—a storage tissue. The red marrow is thought to be the place where the red corpuscles of the blood are formed, which fact makes it one of the most important substances in the body.

The Minute Structure of the Calcareous Portion.—A thin slice of dry bone will show it to be penetrated (Fig. 19) with a great many channels running into each other. These are passages for the blood vessels (Haversian canals). Around the tubes are numerous irregularly shaped spaces (lacunæ), from which the minute passages extend (canaliculi). In the living bone the bone cells occupy the lacunæ, and they receive their nourishment from the blood flowing through the Haversian canals, which can penetrate to them in their stony prisons through the *canaliculi.* These bone cells have for their function the building of walls about themselves of phosphate and carbonate of lime. The walls of one touching those of its neighbor, and becoming fused with it, and they with the next, build up the whole mass of solid bone. This is their special form of activity.



A. *B.*

Fig. 19.

THIN SECTIONS OF DRY BONE.

A, longitudinal; *B*, cross-section. The channels in *A* and the light spaces in *B* are the *Haversian canals*. The black spots are *lacunæ*. The finest lines are *canaliculi*.

If we place a bone in some dilute acid—vinegar, muriatic acid, or sulphuric acid—it will dissolve the lime salts out of the walls and we shall have left the cartilage, the periosteum, the connective tissue of the blood vessels, the two

kinds of marrow, and all the millions of bone cells. If we should burn the bone, all these things would be burned away, and we should have the brittle skeletons of the bone cells lightly held together.

Growth of Bone.—The different parts of the bone grow by the multiplication of its particular cells, as has been said of all the tissues. The blood supplies the nutrition, and the bone cells build up the hard parts, the cartilage cells the elastic parts, and the connective cells weave the fibers of the periosteum and ligaments.

Repair of Bone.—If a bone is broken, cells at the broken surfaces will begin to form new cell surfaces, each kind of tissue cells bridging over the space between the ruptured parts. This repair will take place even if the surfaces are not placed in their proper positions. In such a case, however, the part will be distorted. It is very important to have the bone set and fixed in position by a competent physician, and the sufferer should aid by keeping the parts quiet long enough to allow these processes of growth and repair to finish the work.

The bone, rigid as it is, can, during its growth, be modified in its shape by pressure slowly applied. Consequently, it may be considerably distorted from its natural shape. Improper positions in standing and sitting, or pressure from clothing, if long continued, result in permanent distortion of the bones affected.

Chemical Composition of Bone.—The following table gives the composition of bone, according to the chemist Berzelius:

Gelatin and blood vessels,	33.30
Phosphate of lime,	51.04
Carbonate of lime,	11.30
Fluoride of lime,	2.00
Phosphate of magnesium,	1.16
Soda and sodium chloride,	1.20
	100.00

Gelatin is the substance into which connective tissue is changed by boiling. From this table it is seen that about one third of the bone, without the marrow, is composed of connective tissue.

Articulations.—The place where the surfaces of the extremities of two bones come together is called an *articulation.*

Immovable Articulations.—In some cases, as in the bones of the skull, the bones are immovably joined, allowing no motion. In these the tissue between them is very thin, and projections from each bone interlock with those from the other. Such an articulation is called a *suture* (see Fig. 14). In the case of the vertebræ, except the axis and the atlas, as has been shown, the surfaces of the bodies do not move on one another, but the tissue between them is so thick and elastic that a slight motion to and fro from the direction of their axis is possible.

Fig. 20.

Knee Joint.

Movable Articulations.—In a large number of cases the bones are joined in such a way as to allow free motion on the surfaces of each other. In such a joint (Fig. 20) the surface of the hard part of each bone is covered with a layer of cartilage, and this is covered with a membrane called the *synovial membrane.* The synovial membrane runs off from each surface and extends until it joins together to make a closed sac. The inner surface of the membrane secretes a liquid called the *synovial liquid,* which the sac retains in the joint.

This liquid, which is much like the white of an egg in appearance, reduces the friction of the surfaces, already made as smooth as possible by the cartilage and synovial membrane. The cartilage, being firm and elastic, lessens the effect of jars, and prevents wearing away of the bone.

Fig. 21.

ELBOW JOINT.

Ligaments.—The bones are held in place by very strong bands or cords of white fibrous connective tissue, called *ligaments*. Most of these ligaments pass from one bone over the joint to the other bone (Fig. 21), although in certain cases, as in the hip joint (Fig. 22), a ligament also passes from the head of one bone directly across to the surface of the other bone. The fibers of the ligaments run into the fibers of the periosteum of the bone, and are so interwoven with them as almost to constitute one piece. This makes, consequently, a very strong attachment.

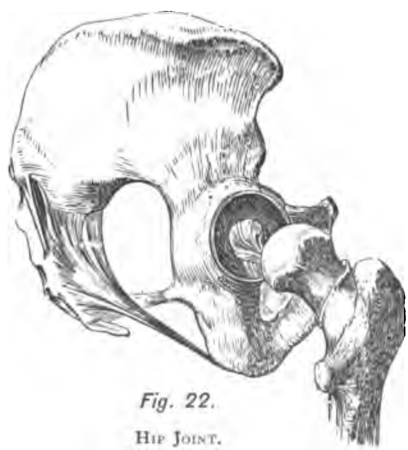


Fig. 22.

HIP JOINT.

The ligaments are numerous, crossing from bone to bone in various directions, so as almost completely to envelop the joint. In certain cases one of the ligaments makes a sheet enveloping the whole joint, as in the hip joint or shoulder joint, in which case it is called a capsular ligament (Fig. 23).

Classification of Joints.—The movable joints are classified according to the kind of motion they permit. The *hinge* joint is one which allows motion in one plane, as do the hinges of a door. The joint between the ulna and humerus, and the one between the tibia and the femur, are examples.

Fig. 23.

SHOULDER JOINT.

The *ball and socket* joint (Fig. 22) is one in which the extremity of one bone is more or less spherical, fitting into a cup-shaped cavity in the other bone. This kind of a joint allows motion in any direction. Examples of this kind are found in the hip joint and the shoulder joint, and less perfect ones in the joints between the fingers and the metacarpal bones.

The *pivot* joint is one that allows motion around an axis, as in the atlas around the odontoid process of the axis, in turning the head from side to side, and in the proximal end of the radius around a point on the end of the humerus, made use of in turning the hand over.

Rigid Joints.—Such joints as occur between the surfaces of the carpals and the tarsals allow very little motion.

Some joints are either modifications or combinations of these different forms of joints.

Dislocation.—A sudden force brought to bear on a joint may tend to throw the surface of one bone off from the other. If this is accomplished, the bone is said to be "thrown out of place," or dislocated. If immediately returned to its place, the harm done may pass away. It is obvious that to accomplish this a surgeon who understands the structure of each joint should be employed.

Sprains.—When a sudden force brought to bear on a joint is not sufficient to dislocate the bone, still the ligaments may be greatly strained or even torn from the bone. This constitutes a sprain, sometimes very painful and slow in healing from the fact that ligaments are very slow of growth. It is a mistake to suppose that a sprained joint should be used a great deal to promote its recovery. If the sprain is a severe one, a surgeon should be consulted, as only a competent person can in such matters decide the exact injury and its treatment.

Directions for Practical Work.

In the study of the structure of bone it must be remembered that only in a fresh bone can all the parts be seen as they are in the body.

Such a one should be examined. Make out its periosteum, its cartilage, its capping, the manner of the attachments of the ligaments. The tendons may have been examined in the study of the muscles. Compare with the figures in the text.

Saw through a bone lengthwise, and note the arrangement of the hard, osseous substances, and of the red marrow and the yellow marrow.

Examine the distribution of the blood vessels in the periosteum and their continuation into the bone.

The same material will furnish a joint or more. By cutting through the outer covering a few drops of synovial fluid can be observed.

Note the perfect smoothness of the surfaces and their close fitting together. Work the joint in every way to see its whole capability. Compare with the figures of joints in the text.

With the compound microscope, the structure of the cartilage, as given in the former section, can easily be shown. (See Fig. 4 B.)

A section of dry bone, to show its microscopic structure, may be made by sawing out as thin a piece as possible with a fine saw, and afterward grinding this down, first on a grindstone or a file, and lastly on a fine razor hone. It should be very thin—thinner than this paper. It can then be mounted dry and examined with the microscope. (See Fig. 19, A and B.)

If a long bone, say the "drumstick" of a chicken, be placed in a dilute solution of some acid for a few days, the lime salts are dissolved and the other parts remain, leaving the bone as flexible as a ligament. If its mate be held on a fire-shovel in the fire a sufficient length of time, all but the lime salts will be consumed, and the brittle skeleton will remain.

Review Questions.

1. Describe a bone.

2. What tissues compose a fresh bone?

3. What is the main use of the majority of bones?

4. What is periosteum, ligament, tendon?

5. How is the bone made rigid?

6. What are the two kinds of marrow, and what is the use of each?

7. What is the minute structure of the calcareous portion of the bone?

8. What are the bone cells, and what is their use?

9. How does a bone grow?

10. What is the process of repair when broken?

11. Why should a broken bone be held in position and kept at perfect rest after being set?

12. What is the effect of continuous pressure on the growth of a bone?

13. What is an articulation?

14. Give examples of immovable articulations.

15. What are the peculiarities of a suture?

16. Describe the articulations between vertebræ.

17. What advantages arise from the arrangement between vertebræ?

18. Describe in detail the structure of a movable joint.

19. In such a joint, what is the function of the cartilage? ligaments? synovial fluid?

20. Describe the ligaments and the method of their attachment.

21. How are joints classified?

22. Describe a hinge joint, and give three examples.

23. Describe a ball and socket joint, and give two examples.

24. Where in the body is a pivot joint? Describe it.

25. What are rigid joints? Give examples.

26. What is a dislocation?

27. What occurs in a sprain?

28. What of the growth of a ligament?

29. What kind of joints are those of the fingers? The one at the point where the lower jaw is attached? At the point where the ankle is articulated with the tibia?

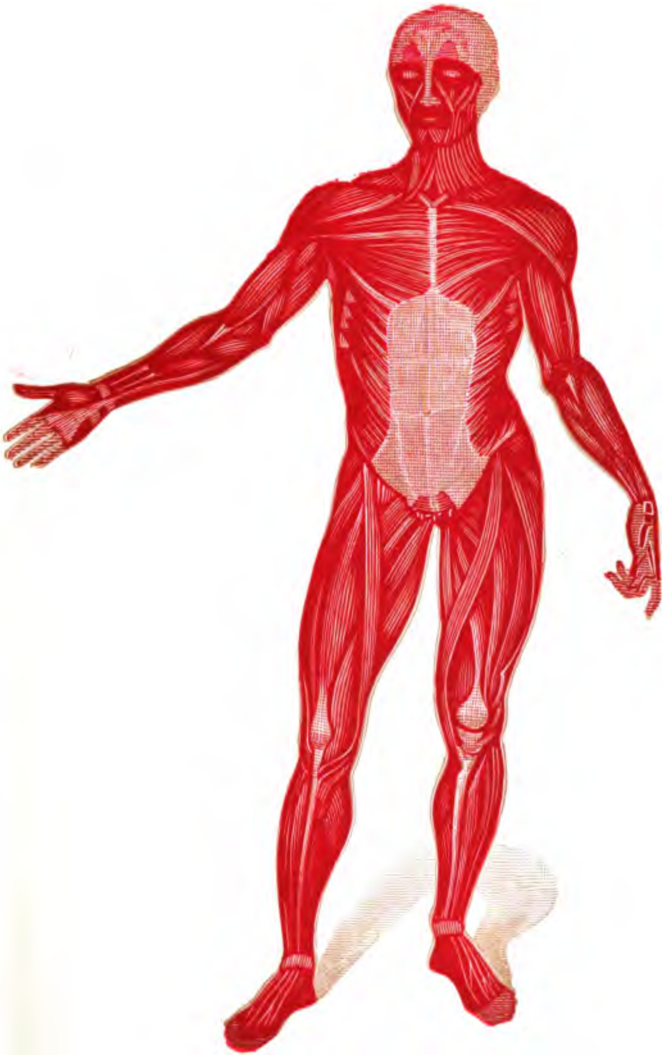


Fig. 24.

ANTERIOR VIEW OF THE SUPERFICIAL MUSCLES OF THE BODY.

AD.—55

Fig. 25.

Posterior View of the Superficial Muscles.

Ad.—56

CHAPTER V.

THE MUSCULAR SYSTEM.

The Source of the Force Producing Movement in the Body.—As we have seen in the former section, the *contractile power* of the muscle is the source of the force by which the movements of the body are accomplished. Contractile substance in the muscles is to the machinery of the body what steam is to a steam-engine. The steam by its power of expansion pushes with great force. The machinist arranges the engine so that this pushing force can act against a piston in such a way as to drive it first forward and then backward, and thus work a system of levers, wheels, and other forms of machinery. If he had a substance which would exert strong pulls instead of pushes, he could work his engine as well. The muscles in the body have the power, under stimulus of the nerves, to contract and make these pulls, which, applied for the most part to the bones as levers, accomplish the movements of the body.

The Number and Distribution of the Muscles.—The muscles are about five hundred in number. The greater number are distributed over the skeleton in such a way as to produce by the various combinations of movements of which they are capable many times that number of motions. (See Figs. 24 and 25.) The remainder are principally placed in the walls of the heart and of the digestive passages.

Classification of Muscles.—The muscles are sometimes divided into *voluntary* and *involuntary* muscles. The *voluntary* are mainly those that are attached to the bones, and for that reason also called *skeletal muscles.* They are spoken of as

voluntary, because they may be called into action by an effort of the will; still, they may also be made to contract in a wholly involuntary way. The *involuntary* muscles are the muscles of the heart, blood vessels, œsophagus, stomach, and the intestines, and those of the middle ear and of the iris.

General Description of a Muscle.—As the properties of the muscles of the two classes differ so little, we will select a voluntary muscle for our study. The appearance of muscles, the manner of their attachment to the bones, and the method by which they produce a motion are best understood by an examination of a muscle in the leg of some small animal seen while still fresh. The leg of a chicken, frog, or toad answers admirably for this purpose. (See notes at the end of the chapter.)

The figure (26) of the *biceps* of the human arm with its bone gives us its form and relation to the bone. In this case the muscle is a thick, spindle-shaped, reddish mass, tapering at the shoulder end into a forked extremity, each part ending in a strong cord of connective tissue attached to the scapula. At the other end it tapers also to a thick, strong white cord of inelastic connective tissue attached to the *radius*. These cords at the extremities are called *tendons*.

Fig. 26.

Biceps Muscle attached to the Radius.

Structure of a Muscle.—A closer examination would show that the muscle is somewhat complex in structure. Its outer surface consists of a tough sheath of connective tissue called the *perimysium*. From this sheath partitions arise which inclose smaller groups of muscular fibers and sup-

port the blood vessels and nerves, which come into the muscle in large numbers. Many fat cells are lodged among the other parts.

Muscle Cells.—The part of the muscle that is contractile—that is, that makes it a source of the force that can be exerted in producing motion—is composed of *muscle cells*. These are among the largest cells of the body, being much longer than broad, and are called muscle fibers, or, sometimes, fiber cells.

Fig. 27.

TYPICAL MUSCLE CELL; MAGNIFIED. E. H.

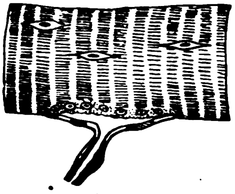


Fig. 28.

A PORTION OF A MUSCLE FIBER, MORE HIGHLY MAGNIFIED, SHOWING THE ENDING OF A NERVE FIBER IN IT.

These differ in the voluntary and in the involuntary muscles. Each voluntary muscle fiber or muscle cell (Fig. 27) is composed of a long sack, the cell-wall, which is filled with muscle protoplasm, the contractile substance of the muscle cell. The cells show on their surfaces very fine lines, and hence they are called striated muscle fibers. A very minute nerve fiber may end in a peculiar way in this muscle substance. In some cases the nerve fiber ends in a mass of protoplasm directly connected with that of the muscle substance, as seen in Fig. 28.

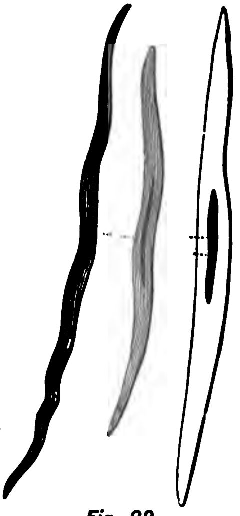


Fig. 29.

MUSCLE CELLS AND FIBERS (INVOLUNTARY).

The shapes of the cells differ somewhat in involuntary muscles (Fig. 29), in all of which, except in the heart, the fibers are long, spindle-shaped cells, with a nucleus in the center.

They show no striations, and hence are called often *unstriated* or *smooth fibers*.

The heart muscle fibers are branched in such a way as to form a network. They are striated, but not so plainly as are voluntary muscle fibers (Fig. 30).

Fig. 30.

FIBERS FROM HEART MUSCLES.

Cause of Contraction.—When a nervous impulse comes along the nerve fiber and arrives at the protoplasm of the muscle cell, it is said to stimulate it, for it causes it to draw up to a shape which is shorter and thicker. Now, these microscopic muscle cells are gathered into bundles just large enough to be seen by the naked eye, and bound together by connective tissue; these in turn into larger ones, and so on, until we have the whole muscle as one large bundle of these smaller groups of bundles. The connective tissue on the outside, making the sheath spoken of, runs off at the ends to form the tendons, which fasten the muscles to the bones.

Thus we may consider the whole muscle as made up of a large community of *muscle fibers*, or cells, bound together in such a way that if they should shorten and thicken about the same time we would have them all pulling together on one big rope, the tendon, which is tied to the bone. Therefore, applied to the bone would be the united sum of millions of individual pulls, which amounts in some muscles to a very strong pull.

Now, the stimulus which comes down the nerve, which distributes its fibers to these muscle fibers, arrives at all the muscle cells at nearly the same time. Thus, a muscle contains myriads of little individual workers which stand ready, day and night, to give a united pull on the bone at any moment the brain or spinal cord may send the impulses. They will contract with just the degree of strength indicated by the strength of the stimulus.

Of course, the workers must have food and oxygen, and this is brought to them by the blood in copious supply, conveyed by the blood vessels which enter the muscle, and, by division into smaller and smaller vessels, at last reach each muscle fiber. The more the cells work the greater must be the supply. This subject of the blood supply to the muscles will be considered again in the chapter on circulation.

Rigor Mortis.—Soon after death the substance of the muscle cell, the protoplasm, becomes rigid. This occasions what is known as death stiffening, or *rigor mortis.*

What Occurs in a Contracting Muscle.—By proper care the muscles of frogs and turtles may be kept alive for some time after removal from the animal just killed. Physiologists have made use of apparatus by which a muscle of a frog can be thus kept and experimented with under careful observation.

From these experiments it is known: *First*, that a muscle will contract and lift a weight when other stimuli are applied to it besides the natural stimulus of the nerve; namely, when stroked or pinched, *mechanical* stimulus; when touched with a hot wire, *heat* stimulus; when many chemicals are applied, *chemical* stimulus; and when electricity is applied, *electrical* stimulus. *Second*, that when a muscle contracts heat is produced in it. *Third*, that carbon dioxide is produced. *Fourth*, that other chemical products of an acid nature are produced. *Fifth*, that oxygen stored up in the muscle is used up. *Sixth*, that certain oxidizable substances in the muscle substance are also used up.

The Muscle as an Engine.—Now, when such a machine as a steam-engine is made to raise a weight, it does so by using up *oxygen*, and an *oxidizable substance*—coal, gas, wood, or oil. In this process it produces carbon dioxide with the giving out of heat. In these points, at least, the muscle-engine and steam-engine are alike. The muscle-engine receives its supply of oxygen and oxidizable substances from

the blood, the blood getting its oxygen at the lungs, and its oxidizable substances from the digested food which finds its way to the blood vessels, as shown in a subsequent chapter.

Waste Products.—The carbon dioxide and other substances which result from this activity (contraction) of the muscle are generally spoken of as waste products. Of these, carbon dioxide is by far the greatest in amount. These are removed by the blood as it irrigates the muscle cells, and are finally eliminated from the body, principally at the lungs and at the kidneys.

Exhaustion, or Fatigue of a Muscle.—From these experiments on the muscle outside of the living bodies of animals, it is found that if a muscle is made to contract repeatedly while lifting a weight it will soon refuse to act, but will again do so if allowed to rest a few seconds. The muscle is said to be "*fatigued*," and this is thought to be due in part to the effect of the accumulation of the substances produced by contraction, and that rest allows these substances to be removed.

When one holds out a weight at arm's length for a few minutes the muscles of the arm will refuse longer to act, from the same causes. Thus with all muscles; they must have their periods of rest to allow the removal of these wastes, and be made ready for new work. Even the heart, which contracts about seventy-two times a minute, remains contracted so short a time that its periods of rest exceed its periods of action.

Relation of Muscles to Bones.—Almost all the voluntary muscles are attached to the bones in such a way as to use them as levers.

A lever is a rigid rod used to lift a weight. One point rests on a fixed support around which it moves, the fulcrum. To another the weight to be lifted is applied; the third point is where the force is applied to lift the weight.

In mechanics, three kinds of levers are recognized, repre-

sented in the diagrams (Fig. 31). *F* is the fixed point of support, the fulcrum; *W* the point where the weight may be considered as resting; and *P* the point where the force is exerted to lift the weight. In Fig. 26, the biceps muscle acts on the radius and the ulna tied together as one bar, supported at the elbow; the weight may be considered to be in the hand. This lever is evidently of the third class. In this case it

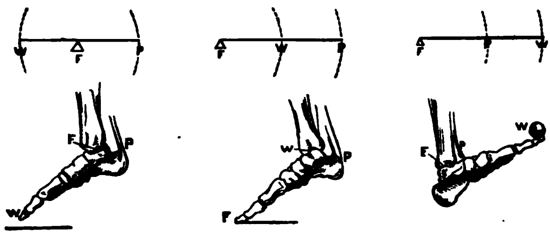


Fig. 31.

FOOT AS LEVERS.

takes a force equal to about six pounds at the muscle point to raise one pound in the hand.

Let the pupil furnish several examples of different levers outside of the body, and then determine in each case what sort of lever each bone is where it is used as a lever. In Fig. 31 the foot is shown as used as each one of the three classes of levers, the first in tapping the toe on the floor; in the second in rising on the toes; in the third in lifting a weight with the toes.

Movements in General.—If one will examine his own body in the positions of standing, sitting, walking, running, and jumping, he may learn much concerning the way the muscles perform these acts.

Standing is accomplished by the action of many muscles in the neck, trunk, and legs. Those on opposite sides pull on the whole in such a way as to make the body a more or less rigid mass, and keep it balanced by compensating pulls over

a small base. Standing really requires considerable exercise of many muscles.

In *sitting*, only the head and trunk are kept rigid, the muscles of the lower limbs being relaxed.

In *walking*, we have a falling movement with the body supported on one leg while it is pushed along by the extension of the other, these conditions alternating between the two limbs. In slow walking, the leg that is off the ground swings to its position by its own weight, and thus the body is moved forward with very little exertion. The exertion is increased with the rapidity of the progress.

In *running*, one leg is quickly flexed, lifted up, and then extended to catch the body as it is thrown forward by a sort of jump produced by a quick extension of the other leg still on the ground. There is a time when both feet are off the ground at once.

In recent years much study has been given to the manner by which the different kinds of motion are accomplished by lower animals, as in the flying of birds, insects, and flying squirrels; in the swimming of fishes, crawling of worms and snakes; the running, jumping, and walking of horses and others of the lower animals. The reader will find the attempt to learn by observation how these motions are produced in these different animals a very interesting study and an excellent means of drill in seeing and thinking.

Tendons.—The tendons by which the muscles are attached to the bones are, both by their mode of attachment and their arrangement, very interesting. As has been seen, a tendon is composed of inelastic white fibrous connective tissue. The fibers are closely packed together and make very strong cords. One no thicker than a lead-pencil is strong enough to support twice the weight of the body. The fibers are continuous with the fibers of the muscle sheath at one end, and are intimately interwoven with the fibrous periosteum on the bone at the other. Indeed, we may

say that the connective tissue of the muscle, of the tendon, and of the periosteum is woven into one piece. One can understand this better if he will examine an example from the limb of some slaughtered animal in the butcher shop, or in the leg of a cat, dog, frog, rat, or any small animal.

By the use of the tendons the muscle can often be placed at a distance from the point where its force is to be applied. For example, some of the muscles which move the fingers are placed in the fore-arm well toward the elbow, thus allowing the fingers and hand to have freer and less clumsy motions than would be possible if the muscles were placed in the hand itself.

The hand is a wonderfully complex piece of mechanism. No figure or model can give an adequate conception of the beauty of its mechanism. Fig. 32 shows the tendon which is attached to the heel, the largest one in the body. The dissection of the foot and leg of some small animal, even of a chicken or a frog, will well repay the trouble it takes to prepare it.

Fig. 32.

TENDON OF ACHILLES AND MUSCLES OF LEG.

Exercise.—While the whole of the explanation of how use and exercise of the muscles will both cause them to increase in size and keep them in a healthy condition is not definitely known, yet the fact that it does so is well known even to those who have not studied physiology. We learned in a former section that at the moment the muscle begins to work great changes are taking place in its cells. Accompanying this activity, by a compensating action of the nervous system, the blood vessels going to the active muscle are relaxed and a

larger amount of blood is allowed to flow through the muscle.

The repetition of these conditions inside of certain limits leaves the muscles in a healthy condition. When the muscles are active the nervous system is equally active, with the same results of increased flow of blood and better condition. When such large portions of the body as represented by the muscles and the nervous system are not in a healthy condition, the effect is a serious one.

We have received our bodies as an hereditary gift from an ancestry which dates back at least to a time when the human race lived an active life in the open air. The human body is adapted to such a set of conditions, and suffers in any other conditions. As we can not change these adaptations, we must supply at least so much of the former conditions as may be furnished by good air and considerable activity.

Excessive Exercise.—We have seen from the experiments mentioned in a preceding section how quickly the muscle may be affected by excessive use, and how rest will restore it. Our experience and observations confirm the lesson there taught. Excessive exercise may result disastrously to the muscles. It must also be remembered that great development of the muscular system does not always indicate perfect health, but it may be, and often is, accompanied by lack of healthy action in other parts of the body.

Forms of Exercise.—The question is often asked, What is the best form of exercise? There are so many good forms of exercise that every boy or girl takes to readily, if only opportunity is given, that a discussion of the particular forms is not necessary.

They are found in the out-door occupations of the farm and house, in the school games, athletic sports, walking, running, riding, boating, bicycling, and tramping through the woods and fields. One could not go amiss among them. The points essential in any case are: 1. That the exercise be

taken in good air—out-door air is the best of all. 2. That it be active. 3. That it bring into activity many muscles of the body.

If any one is so unfortunate as to have no daily employment or no out-door space at his disposal, nor any one with whom to engage in out-door sports, or has no taste for rambles through field and wood, he should nevertheless by all means arrange for daily exercise which can be taken indoors. This has been made possible and pleasant by means of the various apparatus invented for the purpose, manuals for the use of which may easily be procured.

Directions for Practical Work.

A similar preparation to the one made to show the various tissues (the leg of a chicken, Chap. II.) could be used with great advantage in the more detailed examination of the muscles.

In such a preparation be sure to have the muscles well separated from one another. Examine carefully in some one muscle the muscular substance, the muscular sheath, the tendons, and their attachment to the bones.

Note carefully the way in which the tendons shade off into the periosteum in one direction and into the perimysium in the other.

Note how the muscles which move the foot and toes are at a considerable distance from the foot.

Make out the connective-tissue bands, which, acting as pulleys, hold the tendons down at the joints.

Trace out the branches of a nerve into a muscle.

For a more extensive study of the forms and distribution of the muscles, a rabbit answers well.

The body of the animal should be stretched out on a board and tied firmly to it by its feet. This keeps the animal steady during its dissection. An incision is made in the skin along the middle line of the chest and abdomen, and the two sides carefully laid back to expose the muscles underneath. From this incision others are extended down each limb as it is studied.

On removing the skin the superficial layers of muscles are exposed. These will appear as a confused mass, but will be more clear if the attempt is patiently made to separate, one at a time, the larger ones of

these muscles, and to trace out their connections. Do not remove, but simply separate them. As the object is merely to gain a correct notion of the appearance of the different muscles and their manner of attachment and distribution, their names may be neglected.

In this manner, examine at least those of the thorax, the abdomen, the neck, and one of the limbs.

Compare the exposed muscles of this animal with those of the figure of the superficial muscles of man.

One or two students might make the preparation for the whole class.

If the viscera are carefully and cleanly removed, the body of the animal can be kept, if cool, a considerable time without being unpleasant.

Of course, any small animal will answer instead of a rabbit.

If the muscles of a frog or turtle be examined soon after the death of the animal, the muscles can be made to contract by applying the stimuli described in the text.

In a craw-fish or some insect examine how the muscles are arranged to produce their motions.

With a good microscope the fibers of the muscles can be shown by picking apart with needles in a few drops of water a very small piece. A cover glass must be placed over it and pressed down carefully.

It will take other methods, which can not be given here, to demonstrate all the structure of the muscle cell, but this simple method will show well the shape of the fibers and their structure. The muscle fibers of a frog are more easily teased apart than those of the higher animals.

Review Questions.

1. What is the force which produces the motions of the body?
2. To what may muscle substance be compared?
3. How many muscles are there, and how are they distributed?
4. What are voluntary muscles? Give examples.
5. What are involuntary muscles? Give examples.
6. Describe a muscle.
7. How is it attached?
8. What is the minute structure of a muscle?
9. What is the element of a muscle?
10. Describe a muscle cell.

11. What is its relation to the whole muscle?

12. How are the muscle cells supplied with food and oxygen?

13. How are muscles made to contract?

14. What is rigor mortis?

15. Name the six things mentioned as occurring in a contracting muscle.

16. How is a steam-engine enabled to raise a weight?

17. In what are the muscle and the steam-engine alike?

18. What are the waste products?

19. What is the principal one in the muscle? In the steam-engine?

20. What is meant by "fatigue of the muscle"?

21. How is it produced in the frog's muscle?

22. Give other examples of it.

23. What is the cause of fatigue?

24. Define a lever.

25. Draw diagrams showing the different classes of levers.

26. Give examples of each as used outside of the body.

27. Select any five bones in the body which are used as levers, and show how each one is used.

28. Show how the foot may be used as either one of the three classes of levers.

29. Describe the action of the muscles and bones in standing.

30. Describe their action in walking; in running.

31. What are tendons, and what of their composition?

32. What is the use of tendons?

33. What is said of the necessity of exercise?

34. To what conditions has the body been adapted?

35. What of excessive exercise?

36. What are considered to be the essential points in taking exercise?

CHAPTER VI.

STRUCTURE AND PROPERTIES OF THE BLOOD.

The Necessity of the Blood.—The cells in the tissues of the muscles, brain, glands, or whatever other organ, can only do their particular work when well supplied with oxygen and oxidizable substances obtained from food. They are like the single-celled animals in this particular. But these little organisms have an advantage in being immersed in a liquid which may be freely exposed to the air, and, being very small and with thin walls, both those necessary elements may pass immediately to their substance. Thus they do not require any apparatus for conveying food and oxygen to them.

But in the larger animals, composed of millions of cells stowed away in many groups, most of which are buried deep out of reach of external air or food, there arises the necessity of some means of carrying their food and oxygen to these various workers at their different places of work.

This is accomplished by the possession of an internal liquid containing these elements which is conveyed to all the tissues in different ways in different animals. This liquid is the *blood*.

In some animals very low in the scale this liquid is little more than digested food which lies in loose spaces among the tissues and depends on the general motions of the body to move it about.

But in the higher animals and in man there are two liquids, *blood* and *lymph*, both very complex, which are moved about in a very complex system of tubes—*blood vessels* and *lymphatics*—by means of a quickly working force-pump, the *heart*, the whole called the *circulatory system*.

Comparative Study of the Systems of Circulation.—It is very interesting and instructive to study an ascending series of animals and see how in them this system becomes more and more complex and definite, passing from a number of irregular spaces through all stages of imperfection, until the system represented in man is reached. This development is to adapt these animals to a more and more active life and to an increasing size of the body. To seek out these adaptations and observe the development of the mechanisms in animals and plants is one of the most fascinating of studies. We can only refer to such subjects here to call attention to their bearing on human anatomy and physiology.

Human Blood.—The appearance of the blood to the naked eye is familiar enough. But as we now begin its more serious study, an examination of a fresh specimen would be profitable. This may be obtained (a small amount is sufficient) by killing a chicken or other small animal.

Physical Properties of the Blood.—The blood is found to be a liquid, flowing very freely. In the living, healthy body it is a liquid at all times, but when withdrawn from the body it soon solidifies into a jelly-like mass. This process is called *coagulation* and is to be studied later. Its color varies from a bright to a dark red, which soon becomes a brighter red on exposure to the air. Placed in water it will sink, its specific gravity being about 1.055—that is, it is .055 heavier than water. It is slightly alkaline, and possesses a faint odor, which in the lower animals varies somewhat with the species.

While to most persons even the sight of blood is very repulsive, yet in reality the taste of the blood of some animals would not be found to be unpleasant. For example, cow's blood could not easily be distinguished from milk if not seen while tasted. In the body the blood is kept very nearly at 98° Fahr., winter and summer, and in all climates.

The Blood as seen under a Microscope.—A good microscope, magnifying at least three hundred diameters, is

necessary to make out the structure of the blood. If a small drop is prepared properly and examined with such an instrument, it shows the blood to consist of a liquid which, in the small amount used, is transparent, and in which are floating immense numbers of small bodies of definite shape and of pretty constant size. These are the *corpuscles.* They are, like the elements of the tissues, *cells;* but unlike the cells in the tissues, which adhere together in masses, they float free in the liquid.

A closer study shows that there are at least two kinds of corpuscles, which have been named *red corpuscles* and *white corpuscles* or *leucocytes.* But as the red corpuscles so greatly outnumber the white—about four hundred to one—the beginner with the microscope might easily overlook the white corpuscles.

The first time one views the red corpuscles under the microscope he is surprised to find them not red, but of a faint yellowish-red color when seen singly. It is only when in very great numbers in a mass of blood that the multiplied small amounts of red reflected by each corpuscle give the bright red color. Just as a few small particles of ice are transparent, but immense numbers together, as in snow, are white.

Form and Size of the Red Corpuscles.—The red corpuscles are thin disks whose sides are slightly concave (Fig. 33). In size they range from $\frac{1}{3500}$ to $\frac{1}{3200}$ of an inch in diameter. Being so small and so closely crowded together, one drop may contain many millions. It has been estimated that in the blood of a person of average size there are more than twenty-five billions of these corpuscles. But such figures convey no definite conception but that of very great numbers.

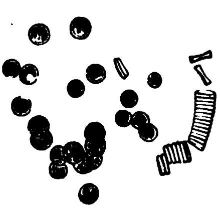


Fig. 33.

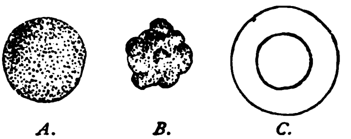
RED CORPUSCLES—HUMAN.

Structure and Function of the Red Corpuscles.—

The red corpuscles are little masses consisting of a groundwork of protoplasm, saturated with a reddish coloring matter. This coloring matter is *hæmoglobin*, and is a substance of the utmost importance, as it has the power of readily extracting oxygen from the air, and after holding it awhile, of giving it up to liquids which have very little oxygen. By means, then, of this hæmoglobin, it is the peculiar and important function of the red corpuscles to take the oxygen from the air in the lungs and to carry it to the tissues and there to give it up.

Origin of the Red Corpuscles.—The corpuscles are continually wasting away through various causes. One source of the supply of these vast numbers is now generally believed to be the red marrow of the bones. There may be other places where they originate.

The White Corpuscles.—The white corpuscles are not nearly so numerous as the red. They number about one white to four hundred red corpuscles. This ratio is not constant, but varies with different conditions. They are irregular in shape and have the power to change their form (Fig. 34). Their motions are exactly like those of the one-celled animals described on page 31, the *amœba* (Fig. 5).



A. *B.* *C.*

Fig. 34.

WHITE CORPUSCLES; MORE HIGHLY MAGNIFIED THAN THE RED IN FIG. 33.

A, as seen floating in the plasma; *B*, changing its form; *C*, after the addition of acetic acid, which makes it transparent and shows its nucleus, the ring in the center.

Structure, Function, and Origin of the White Corpuscles.—The white corpuscles are composed of protoplasm. They are single-celled, and each possesses a nucleus. Their function is not definitely known. One source of their origin is thought to be in the lymphatic glands, where they develop from the cells lining the walls of those glands.

Other Bodies floating in the Blood.—Other forms of

corpuscles and other little bodies have been described as belonging to the blood, but great differences of opinion are held in regard to them, and whether all of them belong to healthy blood or not is uncertain.

In certain diseases, such as splenic fever, and it may be some others, it is known that immense numbers of a few forms of the very low organisms known as bacteria may be found in the blood. (See last chapter).

Plasma.—The liquid part of the blood in which the corpuscles float is the *plasma.* It is very complex. Its constituents are not exactly the same at all times. This follows from the fact that it is constantly receiving additions at various points in its course, and is losing from itself at many points. As it bathes all the tissues of the body, there is a constant interchange of food and waste between it and the tissue cells.

Coagulation of the Blood.—In a former section the fact was noticed that freshly drawn blood would in a short time solidify into a mass of the appearance of jelly, called a clot. This is accomplished by the formation in the plasma of a substance called *fibrin.* The fibrin is composed of multitudes of very fine fibers, which spring up in all parts of the plasma, and run together and join in such a way as to catch the corpuscles in their net work, and make of the whole a tolerably firm body.

Conditions of Coagulation.—The fibrin is not in the blood while it is in its natural vessels and while they and the blood are in a healthy condition, but is formed from certain substances which are always in healthy plasma, ready to make fibrin, and thus clot the blood at a moment's notice when certain conditions are brought about. From this fact, these substances are called *fibrin factors*—that is, fibrin makers. The conditions under which they form fibrin are any injury to the walls of the blood vessels, or contact of the blood with any other substance than the healthy wall of the blood vessel.

From the size of the clot, the fibrin seems to be a large part of the blood, but it is really a very small proportion, about two per cent. of the whole.

Use of Coagulation.—The use of the power of forming a clot is very plain; it is to plug up any blood vessel which may chance to be opened, and thus stop the loss of this precious liquid, which, long continued, even from a small artery, would surely result in death.

Here we have another wonderful adaptation of the body to its conditions. The blood carries in itself substances which will rapidly form plugs to prevent leaking through any opening which may accidentally occur in its system of tubes.

Of course, if a very large vessel is opened, the strength of the current would carry out the blood so fast that death would ensue before this clot could be formed. In this case, the vessel must be tied or compressed a sufficient length of time for the formation of a clot of the size and strength sufficient to stop the flow. For this purpose a surgeon should be consulted. Until one can be called, if an artery is cut, a cord may be tied firmly around the limb above the cut—that is, on the side toward the heart. Just over the artery a knot should be introduced under the ligature, so as to bring all possible pressure to bear on the artery. If only a vein is severed, its flow is easily checked by a ligature on the side of the wound away from the heart.

Serum.—If we remove the fibrin factors or the fibrin from the plasma, that which remains is *serum.* The serum is a watery liquid containing many substances in solution. Indeed, all the food substances for the tissue cells and all the wastes are dissolved in the serum.

The principal ones of these substances are: Proteids, serum albumen, very much like the white of an egg; a small amount of fats; small amounts of many other organic substances not well known; a small amount of inorganic substances, such as common salt, calcium carbonate, calcium

phosphate, and small traces of others. Besides these solids, considerable amounts of oxygen, carbon dioxide, and a small amount of nitrogen are found in the blood.

The following table will show at a glance the main constituents of the blood:

BLOOD,	Plasma,	Serum.
		Fibrin Factors.
	Corpuscles,	White.
		Red.

SERUM contains in 1,000 parts,	Water,	900 parts.
	Serum albumen and other proteids,	85 "
	Fats,	15 "
	Other not well-known organic substances,	
	Inorganic salts,	

Lymph.—Lymph is the liquid which is found in a system of tubes which, like the blood vessels, are distributed all through the body, to be described later. The lymph, while not as conspicuous, is as much a circulatory medium as the blood. Its main supply is the overflow of the blood plasma at the capillaries, which its vessels take up and return to the system of blood vessels.

From this origin of the lymph we might expect it to be of about the same composition as the blood, as indeed it is. It may be described as like the blood without its red corpuscles. It is a liquid like plasma, having great numbers of white corpuscles floating in it, but only occasionally any red ones. The white corpuscles in the lymph come mainly from the lymphatic glands, but also from the blood, by passing through the walls of the capillaries. Their peculiar power of motion allows them to make this passage.

The lymph has, like the plasma, the power of coagulation. As will be seen in the study of the vessels, it, in most cases, comes between the blood and the tissues. That is, the blood

makes its exchanges not directly with the cells of the tissues, but with the lymph, and this lymph makes the exchanges with the tissue cells.

Quantity of Blood.—The amount of the blood in the body has been estimated at about one thirteenth of the weight of the body. That is for the average person about ten to twelve pounds, or about one and one fourth gallons.

Blood of the Lower Animals.—The blood of all the vertebrates contains red corpuscles, white corpuscles, and plasma. In all the vertebrates, except the mammals, the red corpuscles have a nucleus as seen in the corpuscles of a frog (Fig. 35). The form and size of the red corpuscles vary in the different animals, but among the greater number of the higher animals they are so nearly alike as to be distinguished only with great difficulty even by experts. And too much faith is not to be given to their testimony in regard to kinds of blood based alone upon the examination of the sizes and shapes of the corpuscles.

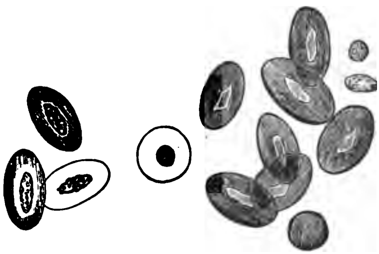


Fig. 35.

RED CORPUSCLES OF THE FROG, SHOWING A NUCLEUS IN EACH.

In the upper right-hand corner are two white corpuscles.

Among the lower vertebrates the range of size is greater. In the common "mud-puppy" or "water-dog" of our streams, the corpuscles are large enough to be seen with a good hand lens. In invertebrates the red corpuscles are generally absent, only the white corpuscles and plasma constituting the blood.

Directions for Practical Work.

The **process of coagulation** may be studied in a cup of blood caught from a decapitated chicken. The blood should be allowed to stand perfectly quiet a day or so. Note the time which it takes the whole mass

to form a clot. Examine closely the clot. Watch the subsequent changes; the clot shrinks and leaves around it a colorless liquid (colorless if undisturbed), which is the serum.

By catching another supply, and immediately before it clots stirring it with a bundle of small sticks or wires, the fibrin can be gathered on the sticks, with the corpuscles left behind in the serum. With the fibrin removed in this way the blood will not clot. This is defibrinated blood. By soaking the fibrin thus gathered in salt water over night the white fibers of the fibrin are plainly seen.

With a Compound Microscope.—A drop of blood may be examined by diluting it with a little saliva and pressing it out very thin. Beginners are likely to make the mistake of using too much blood and of not diluting it sufficiently, and in consequence get such masses of corpuscles as not to be able to see them well. Another matter to be avoided in this examination is the drying up of the liquid. Run a little oil around the edge of the cover-glass to prevent this.

Obtain blood from different animals for comparison of the red corpuscles: a frog, a bird, a toad, a snake, or any of the common domestic animals. For very large corpuscles examine those of the mud-puppy. Examine a drop of blood from some insect and from a crawfish.

Review Questions.

1. What does every cell need in doing its work ?
2. How do the one-celled animals obtain the supply of these substances ?
3. How do cells buried deep in the tissues get the supply ?
4. What is blood ?
5. How does it reach the cells in the different kinds of animals ?
6. What does the comparative study of animals in this respect show ?
7. Describe the appearance of human blood as seen by the naked eye.
8. Describe the appearance of blood as seen under the microscope.
9. What are the corpuscles ?

10. Describe the red corpuscles, shape, size, etc. Illustrate.
11. What is said of their number? Illustrate.
12. Of what are the red corpuscles composed?
13. What is their function?
14. What is the cause of the color of the blood?
15. What is the origin of the red corpuscles?
16. How do the white corpuscles differ from the red?
17. What of their number?
18. Describe their motion.
19. What is their origin?
20. What is said of their use?
21. What is said of other bodies floating in the blood?
22. What is plasma?
23. What is the cause of its changing composition?
24. What is coagulation of the blood?
25. Under what conditions is fibrin formed?
26. What are the fibrin factors?
27. Why do they not make a clot in the blood vessels at any time?
28. What amount of clotted blood is fibrin?
29. What is the use of coagulation? Illustrate.
30. How long does it take a clot to form?
31. What must be done if a large artery is cut?
32. How is a small vein managed?
33. Describe the serum.
34. Give its composition.
35. Write out a table showing the constituents of the blood.
36. Describe the lymph.
37. Where does it come from?
38. How do the white corpuscles get into it?
39. What are its functions?
40. How much blood is there in the human body?
41. What is the appearance of the blood of other vertebrates?
42. What is said of the blood of invertebrates?

CHAPTER VII.

ANATOMY OF THE CIRCULATORY SYSTEM.

The Circulatory System.—The blood is in a system of tubes which form a wonderfully complete net work all over the body. In this system of tubes is placed a double force-pump, which drives the blood with considerable force and rapidity completely around this system. This pump and the tubes are called the *Circulatory System.*

The double pump is the *heart;* the vessels which carry the blood away from the heart are the *arteries;* those which gather up the blood and lead it back to the heart, the *veins;* and the minute vessels which carry the blood over from the last divisions of the arteries to the first divisions of the veins are the *capillaries.*

The heart and the arteries can be compared to an engine and water-pipes of the water-works of a city, the different organs of the body to the houses receiving the water. In the city, however, the water when used from the extremities of the tubes is thrown away or allowed to run off by a system of drain-pipes, that run into a sewer which carries it away from the city. In the body the blood is carefully saved, and what is not used is conveyed back to the pump by either the veins or the lymphatic vessels—two systems of drains—and all this is sent out again and again.

Structure of the Arteries.—To understand how the peculiarities of the flow of the blood are brought about, a knowledge of the structure and properties of the blood vessels is necessary.

The *arteries* are tubes composed mainly of connective tis-

sue, the elastic variety being greatest in amount. There are also in the middle part of their walls muscle cells of the smooth variety. The inner lining is a very delicate membrane, made up of a layer of cells. The muscular part is greater in proportion than the other tissues in the smaller arteries. The arteries are very elastic tubes with muscular walls, which, especially in the smaller arteries, can contract and relax, and thus narrow and widen their openings.

Structure of the Veins.—The *veins* have the same delicate inner lining as the arteries, but the remainder of their walls are thin and have but little elastic connective tissue in them, the inelastic predominating. They also have a small amount of muscular tissue; this is found principally in the walls of the large veins as they enter the heart, or in the very smallest veins.

Many of the veins differ further from the arteries in having folds formed on their inner coats in the form of little pockets which will close against each other or against the opposite side of the vessel in such a manner as to act as valves, to prevent the blood from flowing back from the heart (Fig. 36).

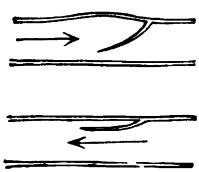


Fig. 36.

DIAGRAM SHOWING ACTION OF VALVES IN THE VEINS.

Structure of the Capillaries.—The minute vessels which connect the extremities of the arteries and the veins—the *capillaries*—are very minute tubes, many of them no larger than is sufficient to give room for a single corpuscle to pass at a time. Their walls are very thin, being composed mostly of one layer of thin cells resting on an extremely delicate net work of connective-tissue fibers. They are easily ruptured, a small amount of pressure being sufficient.

The capillaries form an intricate net work through which the blood flows slowly. Fig. 37 shows the relation of the capillary net work to the arteries and veins. The large, un-

shaded vessel may represent the artery, and the shaded one the vein. The manner of the flow is best seen in the web of a frog's foot, which is thin enough to show under the microscope the wonderful sight of the actual movement of the blood in hundreds of vessels at once. This may also be seen in the fin of a small fish, or in the tail of a tadpole, or in the gills of the larvæ of salamanders.

Fig. 37.

RELATION OF CAPILLARIES TO ARTERY AND VEIN.

Relations of the Capillaries to the Tissue Cells.—It is through the walls of the capillaries that all the changes in the blood take place. The blood capillaries lie in an intricate net work of lymphatic capillaries. In most tissues, the tissue-cell walls touch the thin walls of the lymphatics on one side (Fig. 38), while the blood capillaries touch those walls on the other side.

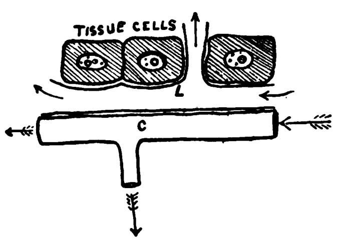


Fig. 38.

DIAGRAM SHOWING RELATION OF CAPILLARY, *C*, AND LYMPHATIC, *L*, TO THE TISSUE CELLS.

Method of Interchange between the Blood and the Tissues. — The exchanges between the tissue cells and the liquid around them is accomplished by the process of *osmosis*. When solutions of many substances are separated from each other by a thin membrane, they tend to pass through the membrane until they are in equal amounts on the both sides of the membrane. Thus, if two liquids are separated by a thin membrane, any salt dissolved in one of the liquids will quickly pass through the membrane until that salt is equally

distributed in both liquids. If sugar be placed in one liquid on one side, and common salt in the one on the opposite side, each will pass to the opposite side until both liquids are equally sweet and equally salt. If a current of water should wash one side of the membrane, it is evident that it would finally remove all the salt from the opposite side.

In the tissue cell, if there has been activity, there will be more carbon dioxide and other wastes than in the lymph. Then these substances will pass to the lymph. The lymph will then contain more than the blood, and they will in consequence diffuse to the blood, and be carried away by its current. On the other hand, the tissue cells will have used up their oxygen, and having less oxygen and other substances consumed in their activity than has the lymphatic by their side, they will now diffuse from the lymph into the cell; then on account of the differences between the state of the lymph and blood, they will pass from the blood to the lymph through the thin intervening walls.

By this means, the cells are always receiving what they most lack and giving off that for which they have no further use. This process is also made use of in taking oxygen at the lungs, and food along the alimentary canal, and passing out the wastes at the lungs, skin, and kidneys.

It may be repeated, then, that the function of the capillaries is to furnish the blood an apparatus by which it may be brought near the tissues, and to furnish a thin membrane by means of which the principle of osmosis may be used to effect the transfer of oxygen and other foods to the cells, and carbon dioxide and other wastes, made by their action, out into the blood. Thus the tissue cells are enabled to live constantly in a medium rich in what they need, and to be constantly purified by the removal of those things which are injurious to them. Not having to seek food and air for themselves, they can devote their whole energy to their specific activities.

The Heart.—The heart is placed in the thorax, between the two lungs, well forward toward the front wall of the thorax, just above the diaphragm, and in about the middle line of the body.

It is in the form of a cone, with its base turned toward the right shoulder. Its apex reaches a point a short distance to the left of the middle line of the body, opposite the space between the fifth and sixth ribs. It is often described as being about the size of the closed fist of the owner.

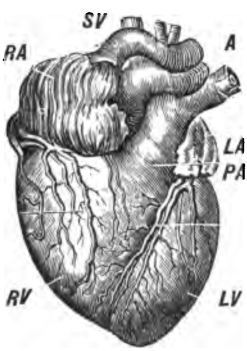


Fig. 39.

THE HEART.

LV, left ventricle; *RV*, right ventricle; *RA* right auricle; *LA*, left auricle; *A*, aorta; *PA*, pulmonary artery; *SV*, superior vena cava.

The large vessels leading away from the heart, as well as to it, come from the base. The heart is suspended from the ends of these vessels as its support. They, in turn, are held to the surrounding parts by connective tissue.

Pericardium.—The outer surface of the heart is covered by a thin membrane, which extends up over parts of the great blood vessels, and turns down again to close in the heart by a sack. This is the *pericardium.* This leaves a space between the outer portion of the sack and the portion on the surface of the heart. In this space is a liquid called the *pericardial fluid.*

The pericardium with its liquid is a contrivance for lessening, as much as possible, the friction against the sides of the heart, caused by its strong, rapid motions.

The Internal Structure of the Heart.—The heart has four compartments, or rooms, the two *auricles* and the two *ventricles*, called in each case the *right* and the *left.* Between the two auricles is a partition, the *auricular septum;* and between the ventricles, the *ventricular septum.*

Valves.—Between the right auricle and the right ventricle is a valve consisting of three membranous flaps of inelastic connective tissue, the *tricuspid valve.* The outer margin of each flap is grown fast to the walls of the heart, while the inner margins are free, except as they are held by strings of connective tissue which extend to the walls of the ventricles.

Between the left auricle and the left ventricle is a valve, the *mitral*, exactly similar in structure to the tricuspid valve, except that it consists of two flaps instead of three, and is heavier and stronger.

Vessels opening into the Heart.—Three large veins open into the right auricle: the *superior vena cava* (descending), the *inferior vena cava* (ascending), and the *coronary* vein (a vein from the heart itself). Into the left auricle four pulmonary veins enter, two from the right and two from the left lung.

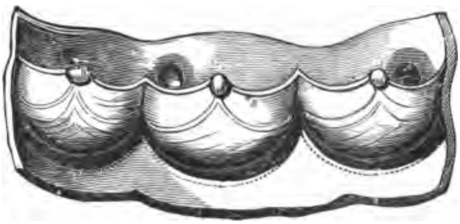


Fig. 40.

The Origin of the Aorta cut open and spread out to show the Semilunar Valves.

From the right ventricle the large pulmonary artery arises, and from the left ventricle the large aorta takes its origin. The origin of each of these arteries is guarded by a valve, consisting of three pouches with the convex sides turned toward the ventricle. They catch the blood whenever it tends to flow back toward the ventricles. This presses their free margins tightly against each other, and the blood is prevented from flowing back into the ventricles. These flaps at the beginnings of the aorta and of the pulmonary arteries are called the *semilunar valves* (Fig. 40).

The Aorta and its Branches.—It is important to

know the location of the great arteries. The aorta, as has been mentioned, arises from the left ventricle. From this point it passes over as a large arch and descends in close proximity to the spinal column. It passes through the diaphragm into the abdominal cavity. Here it descends as far as the last vertebra, when it divides into two large branches, the right and the left *common iliac arteries*. That portion within the thorax is called the *thoracic aorta*.

The first branches of the aorta are two which leave the vessel just above the semilunar valves, the *coronary arteries*. They go to the walls of the heart itself.

Near the top of the arch three large branches leave the aorta. The first is the *innominate artery;* the second, the *left common carotid;* and the third, the *left subclavian.*

The innominate artery is very short and soon divides into two branches: the *right common carotid* and the *right subclavian.*

Both these subclavian arteries pursue similar courses, each leading to an arm. In the neighborhood of the arm-pit it is called the *axillary;* in the arm, the *brachial artery*. In the fore-arm it divides into two main branches, the *ulnar* and the *radial* arteries, each lying along the bone of the same name. They unite in the palm of the hand, forming the *palmar* arch.

Each *common carotid* ascends its side of the neck, and near the head divides into two branches, the *internal carotid*, supplying the brain, and the *external carotid*, supplying, by its branches, the face and the parts outside the skull.

The main branches of the abdominal aorta are: the *phrenic*, going to the diaphragm; the *cœliac axis*, a short vessel, dividing into three branches—the *hepatic*, to the liver; the *gastric*, to the stomach, and the *splenic*, to the spleen; the *superior mesenteric*, a large artery, the main supply to the intestines; and the right and left *renal arteries*, going to the kidneys; the *inferior mesenteric*, going to the intestines. The iliac arteries divide each into two, external and internal. The ex-

Fig. 41.

THE AORTA AND ITS BRANCHES.

AD.—87

ternal branch, which is the larger, supplies the leg, and becomes the *femoral* by the side of the femur, the *popliteal* behind the knee, and below the knee, by dividing, it becomes the *tibial* and *peroneal* arteries, and these unite in the foot by an arch similar to the palmar arch.

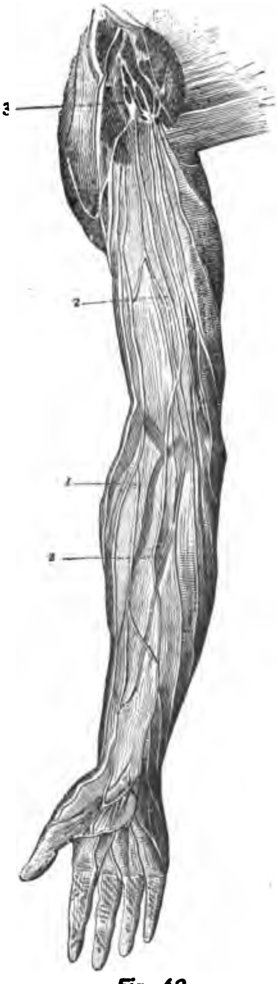


Fig. 42.

LYMPHATICS OF THE ARM.

Of course, all these arteries give off very many branches along their courses. Most of those given above can be traced in Fig. 41. Those going to the viscera are not well shown.

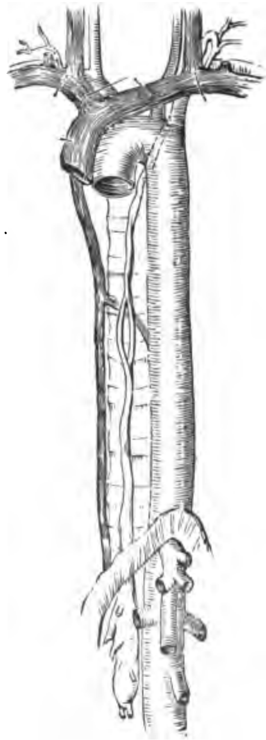


Fig. 43.

THE THORACIC DUCT.

The middle one of the three tubes. It empties into the subclavian vein at the upper right-hand corner of the figure.

Anastomosing of the Arteries.—The branches of arteries often run into each other. This is called *anastomosing*. By this means, if one should become closed, it

does not cut off the supply to parts below, for the blood may run around by some of the many side branches.

The Course of the Veins.—The large veins, for the most part, run by the side of the large arteries, and can be remembered with them.

The Lymphatic Vessels.—The capillaries of the lymphatics, as has been said in connection with the blood capillaries, are distributed among the cells of most tissues, and flow together, forming larger and larger vessels, which are very numerous through the trunk, limbs, and neck. Throughout the course of these vessels are many glands—the lymphatic glands—which have been mentioned as the possible source of the white blood corpuscles. All of these vessels finally empty their contents into the subclavian vein on either side of the body. The larger opening is on the left side, the vessel coming to the subclavian vein here being of considerable size. It is the *thoracic duct.* The one on the right side is much smaller, and is called the *right lymphatic* duct.

Lacteals.—That portion of the lymphatic system which arises in the intestines is called the *lacteals.* Their special function is to absorb digested food from the intestine. This function is discussed in the chapter on digestion.

Directions for Practical Work.

To Study the Heart.—For the examination of the heart, that of a calf, a sheep, or a pig is of the most convenient size, but any heart will answer the purpose.

It is best, in ordering the heart from the butcher, to get both the heart and lungs together, often called the "pluck." If directions are not explicitly given to the contrary, the heart will generally be delivered cut open.

Before dissecting the heart, inflate the lungs and note the relations of the heart to these organs. A hand bellows is convenient for inflating the lungs.

Work carefully and slowly, and do not be in a hurry to cut into your specimen. Indeed, do as little cutting as possible.

Note carefully the pericardium and its relations to the parts around it.

A portion of the diaphragm will be likely to be attached. Open the pericardium and find the pericardial liquid. Also, make out that the pericardium is a double sac.

Attempt to identify as many parts of the heart as you can before removing any thing—the two ventricles, the two auricles, the pulmonary artery, the aorta and its branches, the two venæ cavæ. It is best to fill the vena cava ascending with a roll of paper, to keep from losing it when found. Do not cut into the heart until these are definitely made out.

Now remove the fat from among the vessels, to see more clearly the relations of the great vessels to the heart.

Trace the branches of the pulmonary artery into the lungs, and note along the side of them the pulmonary veins coming from the lungs, and trace them into the left auricle.

Note the aorta, its arch, and the large vessels branching from the top of the arch.

Examine the two venæ cavæ, and note how the muscular portion of the auricle seems to be continued into their walls. Note the difference in the appearance of the large veins and the arteries.

Make an incision across the right auricle so as to show an inner view of the cavity, where may be seen the large openings of the venæ cavæ, and the opening of a large vein—in the sheep the azygos vein—into which, a small distance back, the coronary vein opens. Examine the opening to the ventricle. By dashing water into it, the parts of the tricuspid valve may be raised and closed together.

Note that the walls are composed of many columns of muscles.

Make an incision in the wall of the right ventricle. Through it examine the tricuspid valves from below. Find the method of attachment to the walls of the heart, and see the strings of connective tissue (chordæ tendineæ) running from their margins to the lumps in the sides of the ventricle, which are the papillary muscles. Note other fleshy columns in the walls.

Find the passage to the pulmonary artery; lay it open, and find the semilunar valves and note their structure.

Study the left side of the heart in just the same way as directed for the right, making out the structure for the inner surfaces of the left auricle, the openings of the pulmonary veins, the mitral valve, the chordæ tendineæ, the columnæ carneæ, the opening into the aorta, and the semilunar valve.

Study each part in the left with each corresponding part on the right.

Compare the large arteries with the veins in regard to their elasticity, the thickness of their walls, and their size.

Study the Arteries.—All the arteries given under the topic, "The Aorta and its Branches," can be traced out in a dog, cat, or rabbit. This will be made easier by filling the arteries with some colored substance. Still, the arteries may be traced without this injection.

A good substance may be made of glue or gelatine by soaking a sufficient amount in cold water for several hours. Pour off the water that the glue has not absorbed. Melt the glue in a vessel placed in another containing water (water bath), strain it through a coarse cloth, add some coloring substance, and inject with a syringe into the aorta at its origin. This must be done while the glue is warm, the artery ligatured, and the injected body allowed to remain until the glue is cold. Many of the common coloring substances may be used with which to color the glue. A good one can be made by mixing solutions of sugar of lead and bichromate of potash. The yellow substance thus formed is allowed to settle at the bottom of the vessel, the upper liquid poured off, clean water added, and the process repeated several times to wash the substance thoroughly. It is then warmed and mixed with the warm glue mixture.

If care is taken the finest arteries may be traced by this means. In tracing out the arteries the process ought to proceed slowly and with as little cutting as possible.

If a little carbolic acid is added to the injecting mass the specimen may be kept sufficiently long to study it carefully.

The viscera should, however, be soon removed.

Let not the trouble of preparing an injected specimen be the means of preventing the study of the arteries. They can be made out quite well in an uninjected specimen.

Review Questions.

1. What constitutes the circulatory system?
2. What comparison is made?
3. In what points do the two differ, and in what are they alike?
4. Describe the structure of an artery.
5. How does a small artery differ from a large one?
6. Describe the structure of the veins.
7. Describe, with a diagram, the valves and their action.
8. Give the structure of the capillary blood vessels.
9. What are their relations to the veins and arteries?

10. What is the inter-relation of the blood capillaries, lymph capillaries, and tissue cells?

11. How do the tissue cells get their supply from the blood?

12. Explain the action of osmosis. Illustrate.

13. Where else is it made use of in the body?

14. State the function of the blood capillaries.

15. How is the principle of the division of labor shown here?

16. Give the position of the heart.

17. Describe it.

18. Describe the pericardium. What is its use?

19. Describe the cavities of the heart.

20. What is the tricuspid valve, and what is its structure?

21. Describe the mitral valve?

22. What veins enter the heart, and at what places?

23. What are the semilunar valves?

24. What is their action?

25. Give the location of the main veins.

26. Trace these on Fig. 41, as far as shown.

27. Draw a diagram representing their distribution.

28. What is the anastomosing of the arteries?

29. What purpose is served by this arrangement?

30. What is the course of the veins?

31. What constitutes the lymphatic system?

32. Where does the lymph empty into the blood?

33. What is the difference between the lacteals and the other lymphatics?

CHAPTER VIII.

PHYSIOLOGY OF THE CIRCULATORY SYSTEM.

Course of the Blood in Circulation.—The diagram (Fig. 44) represents a general outline view of the path the blood takes through the body. If we select the right auricle as the starting place, we may say that the blood passes from it past the tricuspid valve into the right ventricle; from this it is forced past the semilunar valve into the pulmonary arteries, from which it goes to the capillaries of the lungs.

From the lungs the pulmonary veins bring it to the left auricle; thence it is pushed through the mitral valve into the left ventricle; from this it is forced past the semilunar valve of the aorta into that vessel.

By this vessel and its great branches above described, it passes to the capillaries in the tissues almost everywhere. From thence it is received by the smaller veins and by larger and larger ones until it is at last brought to the right auricle, thus having made the complete circuit of the body—passing the heart twice in the circuit. That part of the whole system which leaves the right ventricle and returns to the left auricle is called the *pulmonary circulation*. The remainder is known as the *systemic circulation*.

The Portal Circulation.—A portion of the circulation is known as the *portal circulation* (shown in Fig. 44). The blood which comes to the spleen, the stomach, and the intestines, passes first through the capillaries of these organs, and then by their veins, into one—the *portal vein*—which goes immediately to the liver, where it again breaks up into capillaries in that large organ. These unite into the hepatic

vein, which empties into the inferior vena cava. Thus the blood which traverses the vessels of the portal circulation passes through two sets of capillaries before it returns to the heart. The liver, it may be remembered, also receives blood by the hepatic artery.

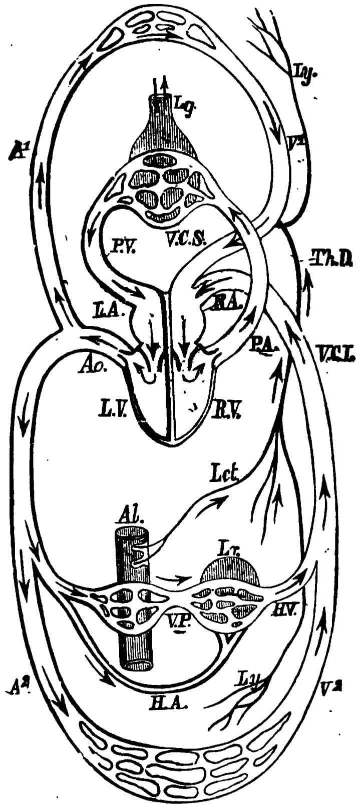


Fig. 44.

LA, left auricle; *LV*, left ventricle; *RA* and *RV*, right auricle and ventricle; *Ao*, A^1, and A^2, aorta and branches; *PA*, pulmonary artery; *Lg*, lungs; *Lr*, liver; *Al.* alimentary canal; V^1, V^2, venæ cavæ, descending and ascending; *VP*, *HV*, and *HA*, portal vein, hepatic vein, and hepatic artery; *Ly*, lymphatics; *Lct*, lacteals. The open nets represent capillaries.

Blood Pressure.—Every one is familiar with the fact that if an artery is cut the blood spurts from it with considerable force, but if a vein of the same size is severed, the blood runs in a steady stream and with but little force. Now, if a glass tube could be connected with the artery, say the carotid in the neck, and another with the jugular vein by the side of it, and these tubes fixed in an upright position so that the blood could rise in them, it would rise in the carotid tube several feet, while in the jugular vein tube it would rise but an inch or two, if at all.

This experiment has been tried on some of the lower animals. Where a dog is

used, the blood in the tube connected with the carotid artery rises about six feet, the height varying with different conditions; in the vein it rises but an inch or two, or even less.

This experiment teaches that the blood in the system of arteries is under great pressure—great enough to support a column of blood, which is somewhat heavier than water, six feet high in so small an animal as a dog. In man the pressure is even greater.

It teaches us further that in the veins the blood is under very little pressure. It is this great difference of pressure between the systems of arteries and of veins which causes the blood to pass from the arteries to the veins.

It is as if the blood were in two tanks—the arterial and venous—connected by small tubes, the capillaries. But the difference between the level of the liquids in the two tanks is six feet or more. This difference would, of course, make a strong flow from the arterial to the venous tank. The pressure that the blood is under in the arterial system is known as *arterial pressure*. It is greater at the origin of the aorta and diminishes toward the capillaries.

Cause of Arterial Pressure.—To obtain a clear idea of how arterial pressure is brought about, we may consider the aorta and its branches alone; and, further, we may for a moment consider them empty. Now, as the left ventricle at the heart would send out six ounces (nearly three eighths of a pint) of blood at each beat, in a very few beats the system of tubes would be filled.

Each succeeding beat adding its six ounces would more than fill the tubes, when the blood would begin to run through the capillaries into the veins. But as the capillaries are such minute vessels, they offer considerable resistance to the flow. This acts as a sort of dam to the progress of the blood. But as the ventricle with great force keeps up its incessant beating, the very elastic walls of the

arteries stretch a little to hold the extra amount. The elasticity of the walls of the arteries will, of course, react on the blood and force it on through the capillaries, even between the beats of the ventricle.

The final result of the combination of these three elements —(1) the beat of the ventricle, (2) the resistance of the capillaries, and (3) the elasticity of the walls of the arteries—is to bring about that state in the arteries in which the pressure is just great enough to force through the capillaries a sufficient amount of blood between the beats, which, when added to that which passes during the beats, will equal the whole amount sent into the arteries by the ventricle during the same period.

Activity of the Heart.—The heart is an extremely active organ. If one could remove the parts that conceal it and see it in the actual work of pumping the blood-stream along, he would be astonished at the force and rapidity of its action. As detailed in another section, it pumps the blood against the pressure which for the left ventricle amounts to a column of blood six to eight feet in height. These vigorous strokes are repeated, on an average, seventy-two times per minute, night and day.

Work done by the Heart.—Each portion of the heart handles about six ounces of blood at each stroke. It has been estimated that the whole work done by the heart in a single day is equivalent to raising a weight of one hundred and fifty pounds, thirty-three hundred feet high. This would be equal to the work done by a man of that weight climbing a height of thirty-three hundred feet, which is about six times as high as the Washington Monument.

A Cardiac Cycle.—In the movement of the heart, the two auricles contract at the same moment. The ventricles beat just after the auricles, and also keep together in the movements. The whole circle of events which occur in the action of the heart is spoken of as a *cardiac period*, or *cardiac*

cycle. In describing it, we may conveniently begin with the contraction of the auricles.

Action and Function of the Auricles.—A contraction begins in the walls of the large veins, which rapidly runs over the walls of the auricles, bringing them into a sudden, quick contraction. This contraction completely fills the ventricles, and by the rebound of the blood thus suddenly sent into them, the tricuspid and mitral valves are well closed before the ventricles begin to contract. The auricles immediately relax and receive blood from the veins until they contract again.

The function of the auricles is to act as a reservoir for the blood, and especially to fill the ventricles and close the tricuspid and mitral valves, so that each ventricle may waste no time or energy in its work.

Action and Function of the Ventricles.—Immediately at the close of the auricular contraction, the ventricles contract with a somewhat slower but much more powerful action. They force their contents against the semilunar valves with a greater force than that of the pressure in the aorta and the pulmonary arteries. This opens the semilunar valves and allows the blood to be pushed into the aorta and the pulmonary arteries, and their branches. The ventricles completely empty themselves. They then relax. At this moment the force of the blood in the arteries reacts on the semilunar valves to close them, while the tricuspid and mitral valves open and allow the blood which has been accumulating in the auricles to fall into the ventricles, each auricle with its ventricle forming one large room. This state of rest remains for a short time, when the auricular beat begins again and the programme is repeated.

Function of the Papillary Muscles.—The little lumps of muscle in the sides of the ventricles, to which the tendinous cords from the edges of the mitral and tricuspid valves are attached, contract at the moment the ventricles contract. By

this means they hold down to their proper positions the edges of the valves, which might, without this action, be loosened by the shortening of the ventricles in contracting.

The Sounds of the Heart.—By placing the ear over the heart two sounds are heard. The first, an indistinct, slightly prolonged one, immediately followed by a short, more distinct one. The two have been represented by pronouncing the syllables, lŭbb, dŭp. But they are best understood by listening to the heart pronounce them. Much dispute has arisen as to the cause of the first sound, but the evidence seems to prove that it is caused by the shock at the closure of the mitral and tricuspid valves. The second is plainly caused by the closure of the semilunar valves.

The Pulse.—When the left ventricle by its sudden impulse forces its contained blood into the aorta, the walls of the whole arterial system spring out a little—the expansion beginning at the root of the aorta and running like a wave through the whole length of the arteries.

The shock of this expansion can be plainly felt on the arteries, and is called the *pulse*. When the arteries come near the surface, as the radial artery at the wrist, the tip of the finger can detect the pulse wave. There are several other points where the pulse may be felt.

The pulse is used by the physicians to learn the rate of the heart's action, the character of its action, and the condition of the walls of the arteries. These may be to him evidences of significant facts in disease.

A pulse also exists in the pulmonary arteries. It disappears in the capillaries, and is absent in the veins. In very rare cases it may appear feebly in these vessels.

Rate of the Blood Current.—The time that it takes for the blood to make a complete circuit has been found by experiments on lower animals. From them it is estimated that in man the time is about thirty seconds. It is not probable that all the blood is circulated in that time, as some

may be easily detained by various causes, but that it is possible that some of the blood may make the rounds in that time.

The blood rushes very rapidly along the arteries, very slowly through the capillaries, and at a steady but moderate rate through the veins. This results from the fact that the aggregate capacity of the capillaries is six to eight hundred times the capacity of the aorta. The united caliber of the large veins as they enter the heart is about twice that of the aorta. Of course, the rapidity of a stream carrying the same amount of blood will be slower proportionately to the size of the stream.

We may recall that the whole object of the circulation is to bring the blood to the capillaries, where the exchange between tissue cells and blood can take place. This requires immense surface, slow motion, and an absence of pulsation, and we have seen how admirably these necessities have been met.

Means for Regulating the Flow of Blood.—A little reflection would show us that the body has some way by which the flow of blood is modified. For example, the face sometimes turns pale, at others it turns red, due to the amount of blood in the skin of the face at the time. These changes may take place rapidly, and are caused, we say, by various emotions. But what we wish to inquire into now is how the circulatory system accomplishes these changes.

These occasional changes which take place in the skin of the face are constantly occurring in other parts of the body, The inner wall of the stomach, when digestion is going on, turns red with the large amount of blood, and turns pale during rest. So with the glands, the muscles, and the brain. Whenever any one of them is in activity, large amounts of blood can come to it. Indeed, this is a necessary condition for its activity. When they are at rest, but small amounts, comparatively, flow through them.

Nervous Control of the Small Arteries.—The increase or decrease of flow to any one organ is accomplished by the action of the muscular walls of the small arteries and their veins. When any organ becomes active, nervous impulses come to the muscle fibers of its small arteries and cause them to relax. The blood, as has been shown, being under great pressure in the arterial system, immediately rushes into the relaxed arteries and fills the organ with a larger amount.

When the activity of the organ ceases, other impulses come to the muscle cells of the small arteries, and cause them to contract, and thus narrow their caliber and lessen the amount of blood supply.

It is as if there were a number of faucets at the ends of the arteries in each organ, which, by means of the nerves, could be turned off and on as the demands of the organ require. Or, again, the body could be compared to a farm watered by irrigation, where a system of ditches leading from a great reservoir allows the farmer at his pleasure, by opening and closing the various sluices, to flood with water any field or bed of plants he might select to receive it.

Nervous Control of the Heart.—The heart is, of course, the most important factor of all in maintaining the circulation and in getting up the high arterial pressure which renders the regulation of the local blood supply possible. The rapidity and strength of its beats are carefully adjusted to the important problem of keeping the blood pressure at the proper point.

In the first place, it has its own little nervous system of ganglia and nerves (see chapter on Nervous System), which can keep it beating independently of the rest of the nerves. The heart of a frog or of a turtle or of many other animals, even of so high an order of mammals as the dog, has been removed from the body, and by methods known in physiological laboratories, has been kept alive some time when care-

fully handled and fed with good blood. In these conditions, the heart has been known to beat for hours, sometimes for days, in a frog or a turtle, pumping blood from one vessel to another. In these cases the beating is accomplished through the heart's own nervous system.

Besides these nerves, at least three sets of nerve fibers come to the heart:

1. A set of fibers to carry impulses from the heart to the medulla oblongata (a part of the brain). These report the condition of the heart to the nerve center. These fibers are in the *pneumogastric* or tenth cranial nerve. (See Fig. 45.)
2. A set of fibers which bring impulses to the heart to slow its motion. These fibers come from the spinal accessory nerve, but reach the heart from the pneumogastric nerve. (See Nervous System.)
3. A set of fibers that bring impulses to the heart, and which quicken its motions. These are fibers from the sympathetic system.

The relations of these nerves to the heart and to the central nervous system are shown in the diagram in Fig. 45, in which *S* represents the sensory fibers from the heart—the words "slows" and "quickens" are placed by the side of the nerves that accomplish these actions; *C*, nerves that cause constriction of the small arteries; *D*, nerves that cause them to relax. The sacs following are to represent the capillaries of two organs—for example, the stomach and the muscles of the leg.

For example, if while one is at rest his pulse be counted, it will be found to average about seventy-two pulsations per minute. If his face be observed, it may be of its usual pink color. Now, if he, as quickly as possible, climb a steep hill or run up several flights of stairs, or perform any other violent exercise bringing into play a large number of muscles, and within two or three minutes after this exercise has begun

the pulse be counted, it may reach the rate of one hundred and thirty per minute. At the same time the face may be pale.

This is what is occurring: The muscles, thrown into violent action, are consuming the food and oxygen in them and making a large amount of carbon dioxide. This requires an increased flow of blood through them to supply the one set of substances and to remove the other. Nervous impulses go from the muscles to the nerve centers (brain and spinal cord), which report these needs. Immediately impulses go down the nerves to the walls of the small arteries in the muscles (Fig. 45), which relax the arteries.

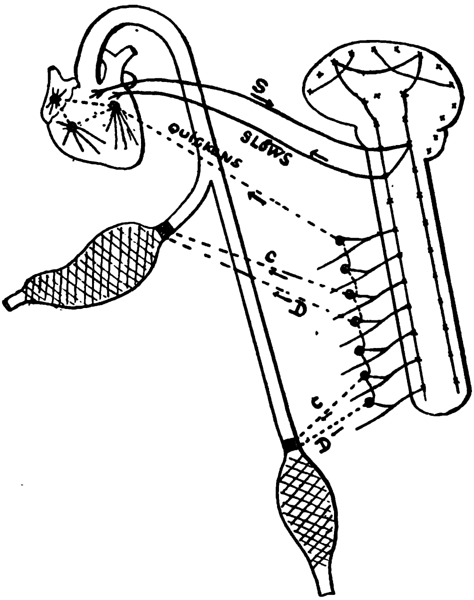


Fig. 45.

DIAGRAM TO SHOW THE NERVOUS CONTROL OF THE HEART AND ARTERIES. (E. H.)

For explanation, see text.

Such a large number of arteries as it takes to supply the great number of muscles in action, opened at once, drains the blood off from the other parts, as seen in the paleness of the face, the small arteries of which may even contract to help throw the blood to the muscles. This would tend to reduce the arterial pressure. Nerves bring to the nerve centers impulses indicating this fact, and immediately impulses go out to the heart by

other nerve fibers (Fig. 45) which quicken its action, by which the blood pressure is brought up to its proper height. Soon the new conditions of the activity are provided for. the blood returns to the face, and may even redden it. The heart will gradually return nearer to its normal state.

What is here made so conspicuous by such a large amount of tissue suddenly thrown into activity is constantly occurring in a less obvious way with the various organs of the body.

The water-works system in many of our cities would serve to illustrate some of these points. If a fire occurs in a part of the city, a message is sent from this point to the central office. From this point men are sent to open a fire plug and by means of the hose turn water on the burning house.

If the fire is a very large one, word is sent to the central office, and from this orders are issued to the engine-house containing the great pump, the result of which causes it to pump faster and harder to make the water pressure greater. And, in addition, it may happen to be necessary to turn off the water from other parts of the city to have a sufficient supply to put out this fire. But the completeness and delicacy with which the circulatory apparatus in the human body responds to its ever-changing conditions far surpasses any human inventions.

Disturbances of the Local Blood Supply.—From the above view of the nervous control of the circulatory system it may be seen why it is not advisable to take violent exercise immediately after a meal. The activity brings great quantities of blood to the muscles, and the process of digestion will suffer from a lack in the supply. The vigorous use of the brain in intellectual activity would disturb the supply to the digestive organs. There is not enough blood in the body to furnish all the organs at once with a large supply. If many organs are brought into activity at once, some or all must suffer. If this action is continued, serious results may follow.

Inflammation.—An inflammation is always accompanied by an excessive amount of blood to the part inflamed. In these parts the blood vessels become relaxed, and much blood in consequence rushes to them.

A cold is an inflammation of some part of the mucous linings of the passages in the head and throat, and may be caused by a chilling of the skin, which causes a contraction of its blood vessels and is accompanied by corresponding relaxation of those of the mucous membranes. Sometimes the cold may be at least partially relieved by producing again a slight inflammation in the skin or a relaxation of its blood vessels, by rubbing it briskly after a bath or by bathing parts of it with a slightly irritating liquid, such as warm water with mustard in it.

This is given here as an illustration of the method of regulating the action of the circulatory system. Other examples will occur, as blushing, turning pale, etc. Drowsiness after a heavy meal is occasioned by a less amount of blood passing through the brain on account of the greater amount turned into the blood vessels of the digestive organs.

Effects of Alcohol on the Circulation.—(For fuller account of effects of alcohol on the body see Chapter XXII., pp. 288–294.) As the heart is so closely connected with the other parts of the body, it is not easy to determine the effects of any single substance upon it. If the substance in question is taken into the stomach, and shortly afterward the heart's action becomes changed, it is difficult to say whether the change is due to the direct action of the substance by its absorption into the blood and its conveyance to the heart, or to its effect on some other organ through which it indirectly and by reflex action influences the heart. Careful and eminent physiologists have shown beyond doubt that when the heart of an animal is separated from the rest of the body and kept alive, the result of experimentation on it with even weak alcohol is to enfeeble its action and decrease its power for

work. It acts thus in the line of depressing and paralyzing the heart, and cannot be regarded as a heart stimulant. The whole discussion of this question would be too long and too technical to enter into at this place. But there is abundant and eminent authority for this opinion, opposed to the older and widely accepted one, that alcohol is a stimulant to the heart's action. The action of alcohol on the heart in cases of fainting and the like is explained as follows : The alcohol works as a sedative to the nervous system, and thus, in the relief from the shock, the heart starts into more vigorous action. The increase of frequency of the heart's beat very often is accompanied by such a decrease of the force of the heart, that the total amount of work done by it is really decreased ; that is, the heart in this condition is less effective as an organ of circulation. This is claimed to be the case when the frequency of pulsation is increased by the use of alcoholic drinks. Large doses of alcohol stop the action of the heart and cause immediate death.

A very common result of taking alcoholic drinks is a flushing of the face. This shows us that the blood vessels of the skin in that region are relaxed. Alcohol probably brings about this change through its effect on the nerve-center controlling these vessels. Reference to a former section will show that the power to change the caliber of the small arteries is an important factor in regulating the amount of arterial pressure and in controlling the blood supply to any single organ. Alcohol disturbs the nice balance maintained in the circulatory apparatus. The result is that the distribution of the blood is not just what the different organs require. While it may not be possible to point out which organ suffers the most, it is obvious that in such a condition the whole body is at a disadvantage. The most marked action of alcohol is on the nervous system. That portion which regulates the circulation shares with the remainder the evil of having false stimuli to guide it in the nervous

responses. Interfering with the circulation disturbs the whole process of nutrition.

The habitual use of alcoholic drinks may lead to serious disease of the heart and of the other organs of circulation. When no direct disease of the heart is traceable to the use of alcohol, still through its continued effects the heart becomes weakened and thus more liable to disease in the future. Its general vitality and tone are impaired, thus rendering it more easily a prey to these diseases. It may become considerably changed in structure ; fat and connective tissue developing at the expense of the muscle cells as in fatty degeneration of the heart.

The smaller blood vessels, through the continued use of alcoholic drinks, are likely to become, in certain regions, at any rate, paralyzed, and they remain in a distended condition. It is said that in the blood itself alcohol has the effect to take from the red blood corpuscles a portion of their oxygen, and thus to interfere with their important function which has already been discussed.

Directions for Practical Work.

To observe the *circulation in the capillaries*, the web of a frog's foot, the tail of a tadpole, the gills of a larva of a salamander, or the tail of a small fish may be used. The part observed is to be kept moist and held under the microscope.

The fish or tadpole can be wrapped in a small strip of wet cloth on a glass slide, in such a way as to leave the tail exposed. The frog may be tied in a similar way to a thin slip of wood (a piece of shingle answers). The foot is to be pulled out, and, by means of threads to the toes, the web is spread over a small hole made in the strip of wood, and firmly tied in this position. The hole allows the light to come through. This web is then placed under the lens.

Study the object with a view to making out at least the motion of the capillaries, the arteries, the veins, the appearance of the corpuscles, both red and white, the relation of all the surrounding tissues, and the changes

which may take place in the parts while under observation. If one is not careful, he is likely to let his surprise at the great activity prevent his making careful observation of the parts. It must be remembered that the motion under the microscope is magnified, and, while it appears very rapid, it is really very slow.

The action of the heart may be well shown in the turtle. It may be killed with chloroform, or by decapitating it. The bony breast-plate must be removed very carefully, when the heart will be exposed in action, which will continue for a long time. Observe carefully the contraction of the auricles and ventricles, the pause, the rate, and the action of the blood vessels.

The effect of heat and cold on the rate of pulsation may also be seen.

The heart of a frog or toad may be used for study in the same way. These are more easily obtained and handled, but are smaller, and of course their action is not so easily seen.

Many of the mechanical principles of the circulation may be illustrated by an india-rubber bulb syringe, a long glass or iron tube, and a very elastic rubber tube. A glass tube with a fine opening may be used as a nozzle. Using the rigid glass or iron tube, and pumping with the bulb, the jets can not be got rid of, but with the elastic tube a steady stream may be obtained, and pressure may be secured which will keep the stream going after the pumping is stopped.

The formation and action of the pulse may also be demonstrated by this apparatus.

Observe the rate of your own pulse in the positions of standing, sitting. lying down, and walking.

Run rapidly up a hill or upstairs, and immediately observe the rate and elevation of the pulse. Observe how long a time elapses until it returns to the usual rate. These experiments may be varied in many ways to show the change of the rate to suit the changes in activity.

Determine the rate of the pulse in some of the lower animals.

Review Questions.

1. Describe the course of the blood in its circulation through the body. Represent it by diagram.
2. What is meant by the portal circulation?
3. Point it out in the diagram given in the book.
4. What is meant by blood pressure?
5. How has it been illustrated?

6. What is the arterial pressure in man? What the venous?

7. Where in the system is the blood pressure the greatest?

8. What causes the blood to flow from the arteries to the veins?

9. How is the pressure in the arteries brought about? Describe in detail.

10. What are the three elements which produce arterial pressure?

11. What is the heart's rate?

12. How much work does it do in twenty-four hours? Illustrate.

13. Name the events of a cardiac cycle.

14. Describe the action of the auricles.

15. What are their functions?

16. Describe the action of the ventricles.

17. What is the function of the papillary muscles?

18. Give the action of the semilunar valves.

19. Give the action of the mitral and the tricuspid valves.

20. What are the sounds of the heart?

21. What is the cause of each?

22. What is the pulse? What is its cause?

23. What does it show?

24. What length of time is required for a complete circulation of the blood?

25. What of the rate in the arteries, capillaries, and veins?

26. What is the cause of the change of rate in these different parts?

27. What is the object of circulation?

28. Why should the blood flow slowly in the capillaries?

29. What are some of the indications that there are means for regulating the action of the flow of the blood? Illustrate.

30. How is the increase or decrease of the flow of blood to a single organ accomplished?

31. Illustrate by a comparison.

32. What nerves control the heart's action?

33. How are they called into action?

34. How do these regulate the heart's action?

35. Explain the diagram in Fig. 45.

36. Illustrate these actions by examples in the body's action.

37. What causes blushing? Turning pale?

38. State now in detail how the local blood supply is regulated.

39. Compare this system and action to a system of city water-works.

40. Why should we not attempt severe work immediately after a meal?

41. Give examples of similar disturbances of local blood supply.

CHAPTER IX.

FOODS AND THEIR RELATION TO THE ACTIVITY OF THE BODY.

Foods.—We do not need to study Physiology to learn that the body must have food and drink. We are not left to find this out by study alone. We are so constituted that any great delay in receiving either develops in us such severe thirst or hunger that we are driven to secure food or drink, even at great sacrifices.

Hunger and thirst are feelings that we are made conscious of through the nervous system, when lack of food and water exists. Hunger and thirst are the result of the working of a certain self-regulating mechanism in the body, the purpose of which mechanism is to bring about what the body demands to continue its existence.

Just why we need food further than to simply satisfy hunger, and what use is made of it when in the body, is not so plainly seen, and needs more careful study. In the first place, it can be easily shown that the human body is constantly losing weight, except at the moment of taking in food or drink. In what form do these substances leave the body?

1st. Every breath thrown out of the lungs carries with it a certain weight of carbon dioxide; a gas composed of carbon and oxygen.

2d. Vapor of water is leaving the skin constantly in greater or less quantities. This consists of hydrogen and oxygen.

3d. Several substances are separated from the blood by the kidneys, to be carried from the body. The

principal one contains carbon, oxygen, hydrogen and nitrogen, and is known as urea.

Even stopping the taking of food will not prevent these wastes. They must go on. They can not cease. The food and drink which we take go to supply the substances from which carbon dioxide, water, and urea are produced. The food alone could not supply the loss occasioned by the removal of these wastes. One other substance is necessary. That is oxygen.

We may say, then, that one object of the food is to replace the wastes constantly occurring in the body. The necessity of this supply and waste is the subject of inquiry later on.

In the above we have considered the case of the body while merely maintaining its weight, but if it is increasing its weight, as in a growing child, it is evident that besides supplying the amount lost by waste, the food is the only source from which to get material for increase in size. Let us now inquire as to the relation of food and oxygen to each other, and of both to the cells of the tissues.

Composition of Foods.— The foods which we know by experience will maintain the body in health and activity have been studied by chemists and found to contain the following classes of substances:

FOODS.	Organic.	Proteids, nitrogenous substances.	
		Fats,	non-nitrogenous substances.
		Carbohydrates,	
	Inorganic.	Water.	
		Salines.	

The *proteids* constitute a group of substances well represented by the white of an egg—egg albumen. Besides this the most common ones are *casein*, found in milk and cheese; *gluten*, found in most grains, being the sticky part in wet flour; *legumen*, abundant in beans and peas; *myosin*, in the lean of meat; and *fibrin* and *serum albumen* in the blood.

These substances are alike in that they coagulate by boiling, and behave in the same way toward several substances (chemical tests). For example, nitric acid or alcohol will coagulate them.

They are all composed of varying proportions of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). Since this group is the only one of the food groups which contains nitrogen, it is often called the *Nitrogenous Group.*

The second group, the *fats,* is familiar enough to need no description. In foods they occur in butter, milk, some grains (corn), nuts, and in the fats of animals. In chemical composition they all have the same elements: carbon, hydrogen, and oxygen.

The third group, the *carbohydrates,* includes in our foods: (1) The *starches,* abundant in grains, vegetables of all kinds, and nuts; and (2) the *sugars,* found in nature in fruits and many vegetables, and manufactured in large quantities from starch. This group is, like the second, composed of carbon, hydrogen, and oxygen, but in different proportions, the oxygen being relatively much more abundant than in the fats. The second and third groups are often termed *Non-nitrogenous Substances.*

It is not usual to make use of any one of these food substances singly. They are found mixed with each other in nature; or, if they are afterward separated as sugar, starch, or fat, before they are taken as food they are again mingled in greater or less proportion. A table of the composition of common foods is given in a subsequent section, showing the relative proportion of nitrogenous and non-nitrogenous food in each.

All of these foods have a considerable amount of water in them, together with some saline substances. The saline substances consist of common salt, carbonates and phosphates of lime, sodium, and potassium, all in small amounts, and with traces of very many other salts.

Relation of these Food Substances to Wastes.—The organic food substances just described are all substances with which oxygen will unite. Outside of the body they can be burned in the air. This burning is the union of the oxygen with the substances at a high temperature. That is, the proteids, fats, and carbohydrates, at a high temperature will unite with the oxygen, and thus be decomposed and form new substances. Such substances as will unite with oxygen are called *oxidizable* substances.

When bread, meat, butter, cabbage, starch, or sugar is burned, and we catch the products of the combustion, they are always found to be carbon dioxide, water, and some substances more or less like urea, containing nitrogen if the substance burned is nitrogenous. That part of these substances which will not burn will also be left in the form of ashes. This contains the salines.

Now, these products of the combustion are exactly the same as the wastes of the body. They are the oxidized substances. The organic foods pass into the body as oxidizable substances. The oxygen passes from the lungs into the body. They both leave the body in oxidized compounds. Somewhere in the passage through the body the oxygen and the food substances, or their derivatives, have united.

Phenomena attending Oxidation outside the Body.—When organic substances are burned outside the body, heat is always given off. If we should burn the grain, meat, or fats in a properly constructed boiler connected with an engine, we would get a great amount of heat, and by it motion could be produced. Most of our machinery is now run by allowing oxygen and an oxidizable substance to unite in a furnace, which, by heating water, will produce steam, which will in turn produce powerful motions. Ordinary food products are too expensive generally for this purpose, so coal, wood, or gas, which are readily oxidizable, is used in just the same way. In

some parts of the United States corn is often cheaper than coal, and is occasionally used for fuel.

Forms of Energy, Conservation of Energy, and Correlation of Forces.—The study of Physics teaches that all the work of the world is done by a few forms of energy. These are the energy of *mechanical position*, producing the visible motions which whole masses may have, such as the falling of water, moving of air, a falling weight, such as a clock weight; or the energy of *molecular motion*, such as heat, light, or the form of energy shown when atoms are combined to form molecules, such as oxygen with carbon to form carbon dioxide, which is called *chemical energy;* or the energy may be that of *magnetic* or *electric condition.*

Energy, like matter, can not be brought out of nothing, nor can it be destroyed. This fact is stated as the law of the *Conservation of Energy.* Just as we can not shape a new form of matter except from material already in existence, so we can not get a single new motion, or raise a single drop of water to a higher temperature, except by the use of some already existing form of energy.

The forms of energy are convertible one into another. That is, by heat we can get motion; by chemical activity we can get heat, or heat may be transformed into light, or chemical action may become the source of both. This convertibility of one form of energy into another is known as the *Correlation of Forces.*

The Source of most of the Energy which works our Machines.—In actual practice we get a great amount of our work done by heat which we obtain by the oxidation of carbon in fuel, such as coal, wood, oil, etc. This is chemical energy converted into heat, which, expanding the steam, pushes a piston, and thus produces motion, which may revolve a body in such a way as to produce an electrical condition, which, in turn, may result in light or heat again. In some cases we wish only heat, as for

warming our houses; sometimes only light, and sometimes only motion.

Machines are arranged to make use of any one or all of these forms of motion. We have examples in the stove or furnace, in the lamp or electric light, or in the moving car, or the wheels of some form of machinery.

In all these cases the source of the energy, we may repeat, is from the chemical energy in the combustion of the coal or other fuel. We may also repeat that the waste of this combustion is always carbon dioxide, and generally water and some compound of nitrogen are also produced. The wastes are always oxidized products, the exact form depending on the kind of the fuel.

Source of Energy in the Body.—The human body can not escape the laws of the physical world. Every motion in it, every chemical action by any cell, every bit of heat produced—in short, every form of activity which it manifests, must also, as in the engine, be produced by the transforming of some already existing form of energy. The form of energy which seems to be the main source of all those shown by the body is that of chemical energy, obtained by the union of oxygen with parts of the tissue cells derived from the food substances. To sum up these points, we may say:

1. Energy is the power of doing some kind of work (mechanical, molecular, or atomic).
2. The chief forms of energy are: heat, light, mechanical (energy of position), electrical condition, and chemical (atomic) condition.
3. Energy can not come from nothing, but one form must come from another form.
4. In most of the processes outside the body the source of the particular form of energy sought is chemical energy derived from oxidation of oxidizable substances—the one from the fuel, the other from the air.

5. In the body the principal forms of energy required are mechanical motion, heat, and chemical action (in growth and secretion).
6. The source of these is, as in the processes outside the body, oxidation of oxidizable substances.
7. The oxidizable substances are in the cells, and are drawn from the food; the oxygen which oxidizes them comes from the air.

Other Substances taken with the Foods.—The water and salines dissolved in it, which are taken with the food, should be considered apart from the organic foods. If they are to be called foods at all, they are so in an entirely different sense from that in which the organic compounds are foods.

Water.—Water taken into the body is probably not at all changed until it leaves the body. Its main uses are: (1) to act as a solvent of substances, so that they may as a liquid move from place to place, and (2) as a means by which transference of substances by the principle of osmosis may occur, the method upon which every cell depends to receive its food or give up its wastes.

Salts.—The salts in the food that the body makes use of serve various functions. Some, added to water, make it a solvent for substances which water alone will not dissolve; others form parts of certain tissues, as salts of lime in the osseous tissue. Of many the function is unknown. Of course, many salts taken with the food are made no use of at all in the body, and may be injurious, as is the case with most mineral salts.

Flavors.—Other substances are mixed with the food by the cook for the purpose of producing pleasant flavors or tastes. These substances are in no proper sense of the term foods, but they serve the very useful purpose of rendering the food pleasant. Other things being equal, food pleasant to the taste seems to be, in general, surer of digestion.

Relative Value of the Organic Foods.—It is evident

that it would be the best economy in the working of an engine, both for the engine and the fuel, to use just the amount necessary to do the work proposed. So in the human body, the use of just that amount and quality of foods necessary to accomplish the work it is doing is the best economy in all ways.

As all the tissues contain nitrogen, their growth and repair absolutely demand nitrogenous foods. These we have seen are the proteids. Experiments have shown that animals fed on non-nitrogenous foods alone will starve. But if more nitrogen is taken in foods than is needed in the nutrition of the body, this requires extra expenditure of energy, and thus there is a waste of the food and energy.

The organs of the body concerned can stand some variation from the normal work, but a great variation long continued would result in injury or disease of the organs. Many diseases have been traced to long-continued taking excess of proteid foods.

The greatest amount of energy that the body manifests is in the form of heat and motion, and not growth. There seems to be what is required for the production of these in the non-nitrogenous foods,—fats and carbohydrates. An eminent authority (Landois and Stirling's "Physiology") makes the statement that "experience has shown that the diet best suited for the body must contain one part of nitrogenous foods, and three and one half, or, at most, four and one half parts of non-nitrogenous foods." The following table of approximate composition of foods from the same source shows how nearly some of our common foods come to containing the proper proportions:

	NITROGENOUS.		NON-NITROGENOUS.
1. Veal,	10	to	1
2. Rabbit's flesh,	10	"	2
3. Beef,	10	"	17
4. Beans,	10	"	22
5. Peas,	10	"	23

	Nitrogenous.		Non-nitrogenous.
6. Mutton,	10	to	27
7. Pork,	10	"	30
8. Cow's milk,	10	"	30
9. Human milk,	10	"	37
10. Wheat flour,	10	"	46
11. Oatmeal,	10	"	50
12. Rye meal,	10	"	57
13. Barley,	10	"	57
14. Potatoes,	10	"	115
15. Rice,	10	"	123
16. Buckwheat meal,	10	"	130

Variation in Amount of Foods.—From the whole discussion of the subject it can be seen that the amount of food any one will need will vary greatly with the work the body is doing and the conditions under which it is working. It is like an engine in this particular also. Exposed to cold weather, more food is needed than in warm weather. More food is needed as the activity is greater. Activity in a cold atmosphere will require still more. When the conditions are the opposites, the body requires less food. The following table, quoted in Landois and Stirling's "Physiology," is instructive:

A healthy adult person requires in twenty-four hours, not including water:

	At rest.	In ordinary work.	Hard work.
	Ounces.	Ounces.	Ounces.
Proteids,	2.5	4.6	6 to 7
Fats,	1.0	3.0	3.5 to 4.5
Carbohydrates,	12.0	14.4	16 to 18
Salts,	0.5	1.0	1.2 to 1.5
Total,	16.0	23.0	26.7 to 31

The facts given in the above tables and statements have been arrived at by a long and careful series of observations and experiments. They teach a great deal and give a rational basis for regulating the amount of food, which,

if carried out on a large scale in a community, would save a great amount of waste of valuable food, and would rid the community of many diseases. This, of course, is impracticable, except in armies or other large bodies of men whose food is served out to them under control.

The Body's Method of regulating the Amount and Kinds of Foods.—While the results of scientific investigation of foods are extremely valuable, yet each one in health has in his own body, as was mentioned at the beginning of the chapter, a portion of the nervous system which reports from time to time his needs in these respects. The effect of lack of food gives rise to hunger; lack of water, thirst.

A need for this or that food and a necessity for change are revealed to us by our likes and dislikes, longing or craving for or loathing different kinds of foods. If we are in health and do not abuse these tastes, but give the proper attention to them, we may cultivate and keep a delicate indicator which will, in a more perfect way than any scientific table has yet done, tell us what is needed.

If one has, from one cause or another, abused his appetite until it is deranged and no longer a safe indicator, he is in great danger, and will have to depend on some other guide until it is regained.

"Dieting."—It is a curious and unpleasant fact that too much consciousness of what is eaten, and too much dwelling on what might be the consequences of this or that kind of food, often brings about serious derangement of the digestive processes.

Many phases of the so-called disease of *dyspepsia* have been brought on by an overconsciousness of the process of eating, the result of attempting to put into practice some particular set of rules of what to eat, what not to eat, and how to eat it. Such people can often recover if they would banish all rules, except the good universal rule of not overfeeding, and think of something else than of what they are eating.

Alcoholic Beverages and Food.—In substances known as alcoholic drinks (for fuller treatment of composition and properties see Chapter XXII, pp. 286–294) alcohol constitutes the characteristic substance. There has been a great deal of discussion as to whether alcohol may be used as a food in the body; that is, whether it can be oxidized and decomposed into carbonic acid gas and water, and thus give rise to energy which may supply the body.

Directly opposite opinions are held in regard to this question. The arguments and evidence are too lengthy and technical to be entered into here. Still it may be said that certain experiments seem to show that, under some circumstances, alcohol taken in small amounts may be partly decomposed in the body, and thus may serve as food. On the other hand, it is clear that much of the alcohol taken into the body is thrown out as such, and consequently could not have served as a food. The whole question has only a scientific interest, and not any practical bearing, for no one really takes alcohol for nutrition, and if it could be unmistakably demonstrated that some of the alcohol taken into the body could act as food, the amount that is thus used is so very small that it can have little importance in this capacity; for other harmless and less expensive articles furnish much better nourishment. A slice of bread and butter is immensely more nutritious than the amount of alcohol that could be purchased for the same price.

Other substances in alcoholic drinks, which are undoubted foods, such as sugar and proteids, are present in but small amounts. Purchased as a part of these drinks, they are most expensive; hence these beverages cannot be considered as important sources of such food substances. On the other hand, the manufacture of these drinks is accomplished by the destruction of vast amounts of the principal food substances of the world, which greatly offsets the little value they may possess as food.

Review Questions.

1. What is the means the body takes to secure sufficient food?
2. How are hunger and thirst produced?
3. How does the body lose weight?
4. When does this loss occur?
5. What supplies the loss?
6. What are the wastes of the body?
7. Of what are they composed?
8. What things occasion the demands for food?
9. What are the classes of food substances?
10. Give examples to illustrate proteids.
11. Of what elements are they composed?
12. What are some of their properties?
13. Give examples of articles of food containing them.
14. Describe the fats and give the sources from which we obtain them.
15. What are the carbohydrates? Illustrate.
16. Where are they found?
17. What is their composition?
18. How are the salines furnished to the body?
19. What is an oxidizable substance?
20. Which are the oxidizable foods?
21. What substances would result from burning the organic foods?
22. What is the evidence that these food substances are oxidizable in the body?
23. What phenomena attend oxidations outside of the body?
24. How is the work of the world accomplished?
25. What are the forms of energy?
26. What is the law of the conservation of energy?
27. What is meant by the correlation of forces?
28. What is the source of most of the energy used in running machinery?

29. Illustrate the changing of one form of energy into another in machines.

30. What are the chief forms of energy manifested in the body?

31. What is the source of these forms in the body?

32. Make a summary of the points in the foregoing discussion.

33. What of the water taken into the body? What are its functions?

34. What uses do the salts serve in the economy of the body?

35. What are the flavors and what purpose do they serve?

36. What is the best economy of fuel in an engine? What is the best economy in the body?

37. Why is nitrogenous food a necessity?

38. Why is too great an amount of nitrogenous food not the best economy?

39. Which group of foods does the body need the most?

40. What is the proper proportion of nitrogenous food for the best economy of food and work of the body?

41. In the table given, which foods show the nearest approach to containing these proportions?

42. Name several mixtures of common foods which will give this proportion.

43. What conditions of the body will vary the demands for different kinds of foods?

44. What is the effect of cold? Of increased activity?

45. How does the body regulate its supply of the necessary kinds of foods?

46. What is the meaning of desires for different kinds of foods?

47. What is said of dieting?

48. In health how may we be guided in the selection of food?

49. How can our natural indicators in this regard be kept as a safe guide?

CHAPTER X.

ANATOMY OF THE DIGESTIVE SYSTEM.

Digestion.—We have now to consider how the food is brought into the blood, by which means it reaches the *tissue cells.* None of the ordinary proteids which we take as foods are soluble in water, nor are any of the fats; and of the carbohydrates, the sugars alone are soluble. All of them must pass through the lining wall of the alimentary canal. This is composed of a layer of cells. This necessitates the reduction of these insoluble substances to a state of solution, or, as in the case of the fats, to a very finely divided state, called an *emulsion.* These processes are *digestion*, and to a great extent are chemical processes in their nature.

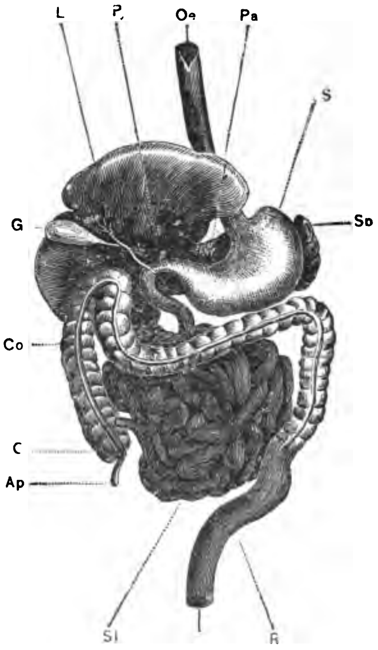


Fig. 46.

ALIMENTARY CANAL.

Oe, œsophagus; *S*, stomach; *P*, pylorus; *Si*, small intestine; *Co*, colon; *R*, rectum; *L*, liver raised up; *Pa*, pancreas; *Sp*, spleen; *G*, gall bladder, from which leads the bile duct; *Ap*, appendix vermiformis; *C*, cæcum.

But as the food substances are enclosed generally in more or less solid or bulky

forms, as bread, meat, beans, fruits, etc., they must be subjected to certain mechanical processes—mastication, swallowing, and other muscular actions—to propel them along. All these processes are accomplished by a series of organs included under the head of the *Digestive System.*

Digestive System.—This consists of the *alimentary canal* and its *appendages*, the organs of which are: the mouth and its appendages (the salivary glands), the pharynx, the œsophagus, the stomach, the small intestine and its appendages (the liver, the pancreas), and the large intestine. The alimentary canal is a long tube which varies in size and form at different positions to make the organs just mentioned.

Mucous Membrane—General View.—Throughout its whole extent the alimentary canal is lined by a sort of skin —the *mucous membrane*—continuous at the lips with the skin on the outer surface of the body. In this mucous lining are imbedded many glands, nerves, and blood vessels.

Glands.—It is the function of the glands to secrete the liquids which are to accomplish the digestion of the food; hence, they stand first in importance in the digestive system.

All true glands are formed on the same plan, their complexity resulting by simply repeating the parts. The essential parts of a gland are a layer of *gland* or *secreting cells*, a thin layer of connective tissue, called the *basement membrane*, to support the cells, a system of *nerve fibers*, and a network of *capillary blood vessels* in close proximity to the basement membrane.

This arrangement allows the blood to circulate freely near the cells, and the lymphatic spaces between allow exchanges between the blood and the gland cells. Thus they may receive the supply of blood on which they depend for the formation of their peculiar secretion. In the simplest arrangement, in which the gland cells are spread out in a flat layer, a considerable amount of surface would be required for a few cells, and, consequently, but a small amount of secretion

could be formed in a limited space. This answers well enough on the surface of certain large cavities, such as the pericardium, or the lining of the abdominal cavity, the peritoneum.

But in most cases the amount of secretion is so great that it could not be furnished except by a great amount of surface. One device by which this increase of surface is obtained is by depressing these elements of a gland into a tube, or sac-shaped cavity. These tubes or sacs may remain single, as the glands in portions of the walls of the stomach or small intestine, or at the roots of the hairs, in which case they are called *simple tubular* or *simple sacular glands*, there being no difference between the two except that of shape.

Compound Glands.—The tubes or sacs in some cases become very much branched, until the whole makes a mass of considerable size, as in the pancreas or liver. By this means the secretory surface is immensely increased. Such is known as a *compound gland*.

A compound gland may be so complex in structure as to be confusing, but it may be easily understood if it is remembered that it is composed of exactly the same elements as the simple gland, with the extremities of these tubes forked, and each of these forks again divided, and so on, like the trunk, limbs, and minor branches of a tree. The secreting cells are at the ends and along the sides of the last branches. Around them is a layer of connective tissue and the network of blood vessels.

The gland cells discharge their secretion into the hollow space of their tube, which empties into the next. The minutest tubes thus run together to form larger ones; these again unite, until at last the secretion is poured into one channel, *the duct*, by which it empties its contents. By the elongation of this duct the gland may be situated at some distance from the surface where the secretion is needed.

Each gland opening into the alimentary canal may be con-

sidered as an extension of the surface of the internal lining of the canal in the direction of the gland, in order greatly to increase the secretory surface. This is another example of the physiological division of labor, in which a portion of the surface of the alimentary canal is withdrawn and set to the task of furnishing the digestive liquids, leaving the rest of the surface to be devoted wholly to other functions. The kinds of glands and their distribution are given with the description of the organs where they are found.

Cause of the Activity of the Gland Cells.—Every gland, as is the case with every muscle, is supplied with a nerve whose fibers are so distributed as ultimately to reach the gland cells. The nervous impulses brought to the gland cells by the nerve fibers are the cause of the activity of the cells in the act of secretion. The nervous impulses arise in the nerve centers (brain and spinal cord) in the manner described in the chapter on the nervous system. This arrangement puts the glands under a control, so that they may secrete the proper amount and at the proper time.

The Mouth.—The mouth has for its roof the hard and soft palate; for its floor, mainly the tongue; for walls, the lips in front, the cheeks at the sides, and part of the soft palate behind. The lips form the door that can be opened and closed in front; the soft palate, a curtain which may be dropped over the opening at the back. Standing out very prominently in the mouth are the teeth.

Mucous Lining of the Mouth.—The mucous membrane of the mouth, like the skin, consists of two layers. The outer layer consists of epidermal cells packed closely together, with their walls cemented together so that the whole presents a pretty firm protecting layer. The lower layer is composed of fibers of connective tissue, which serve as the support of numerous glands, blood vessels, and nerves. In many places the lower layer is raised into minute elevations called *papillæ*, in which is a network of blood vessels and nerves.

These papillæ are on exactly the same plan as those of the skin. In the mouth they vary much in shape, size, and function. In the lips the papillæ contain touch organs, as in the skin on the palm of the hand. Over the surface of the tongue are distributed four kinds of papillæ:

1. Ordinary *touch* papillæ, mostly on its tip.
2. *Fungiform* papillæ, which are large enough to be seen with the naked eye as smooth, bright red dots scattered over the surface of the tongue.
3. *Conical papillæ*, which are very numerous, filling in between the fungiform papillæ, but disappearing toward the base of the tongue. Over some of the conical papillæ are developed brush-like coverings, the whole giving the tongue a soft, velvety surface.
4. The large *circumvallate* papillæ, varying from seven to twelve in number. These are on the back part of the tongue in a V-shaped row. They are eminences of considerable size, standing in depressions. In the bottom and sides of these depressions there are imbedded in the epidermis numerous flask-shaped groups of cells, which are regarded as organs of taste. They, as well as all other papillæ, are well supplied with nerves

Fig. 47.

TEETH OF THE LOWER JAW.

The teeth are in reality greatly developed and curiously formed papillæ.

The Teeth.—The teeth occur in two sets. The first set, twenty in number, the *temporary teeth*, is that of childhood, which is replaced later by the second set, the *permanent teeth*, thirty-two in number.

The first set appears at about the time the child is able to take solid foods, usually in successive order from the front backward. They are gradually replaced by the second set in about the same order, in slow succession, as the jaws become large enough to accommodate them; the last one on each side, "the wisdom tooth," appearing about the time the body gets its growth.

Names of the Teeth.—In each jaw the first four teeth are the *incisors;* the next in order, one on each side, the *canines;* the next, two on each side, the *bicuspids* or *premolars*, and the last, three on each side, the *molars.*

The Dental Formula.—For convenience in making comparison of the teeth of man with those of the lower animals, a formula is used. The dental formula for man is:

$$\text{I.}\ \frac{2-2}{2-2};\ \text{C.}\ \frac{1-1}{1-1};\ \text{PM.}\ \frac{2-2}{2-2};\ \text{M.}\ \frac{3-3}{3-3};$$

in which the numerators show how many of each kind of teeth are in each half of the upper jaw, while the denominators show the same for the lower jaw. For example, the dental formula for the cow is:

$$\text{I.}\ \frac{0-0}{3-3};\ \text{C.}\ \frac{0-0}{1-1};\ \text{PM.}\ \frac{3-3}{3-3};\ \text{M.}\ \frac{3-3}{3-3};$$

for the horse is:

$$\text{I.}\ \frac{3-3}{3-3};\ \text{C.}\ \frac{1-1}{1-1};\ \text{PM.}\ \frac{3-3}{3-3};\ \text{M.}\ \frac{3-3}{3-3}.$$

It would be instructive to compare with your own teeth those of other animals that are accessible. Both the number and forms of teeth of animals vary greatly, being adapted to the many different kinds of food on which they subsist, and to very different actions from that of mastication. Indeed, the main use of the teeth among most lower animals is not for mastication.

Structure of a Tooth.—Three parts are distinguished in

a tooth. The part projecting above the gum is the *crown;* the portion surrounded by the margin of the gum is the *neck;* and the portion (single in some, branched in others) which extends into the jaw-bone, the *root.* A section through a tooth taken lengthwise (Fig. 48) shows it to consist of a hard portion surrounding a soft central portion which extends through the core of the roots. This is called the "pulp." It consists of a network of blood vessels, lymphatic vessels, a nerve with its branches, and a certain amount of connective tissue supporting these. The vessels and nerves come in at the points of the roots. The pulp occupies the central portion in Fig. 48.

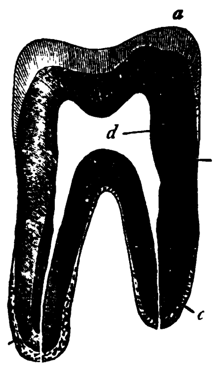


Fig. 48.

SECTION OF A TOOTH.

a, enamel; *d*, dentine; *c*, cement. The open space in the interior contains the pulp in a living tooth.

The hard part of a tooth consists of three kinds of substance: the *dentine* (*d*), which immediately surrounds the pulp and forms the main body of the tooth; the *enamel* (*a*), which is a plating covering the crown portion of the dentine; and the *cement* (*c*), which plates the root portion of the dentine.

The *dentine* is a very hard substance, which the microscope shows to be penetrated by immense numbers of very fine tubes, which allow plasma from the blood to penetrate it, and also promote the distribution of some of the finest of nerve fibers. The ivory of commerce is the dentine of the tusks—certain large teeth—of elephants and some other animals.

Enamel is harder than dentine, being the hardest of all the body tissues. It is composed of small, rod-like cells, very closely packed, and firmly cemented together.

Cement is of the same substance as bone, and is covered with a sort of periosteum, as is the bone. The root of a tooth extends into a hollow in the jaw, the lining of which is peri-

osteum, which is continuous with the periosteum covering the root. The fibers of the connective tissue of all these layers are interwoven with those of the gum, and by this means the tooth is very firmly held in its cavity in the jaw.

Uses of the Teeth.—The primary use of the teeth in man is plainly for dividing and crushing the food. By the many methods of grinding, crushing, and otherwise preparing the food, together with the processes of cooking which civilized peoples use, the work of mastication has become very much lessened. By the aid of these methods it is possible to get along, although not very well, without any teeth. Nevertheless, as they are of very great convenience in mastication, and invaluable in articulation, they are well worthy of great care.

Care of the Teeth.—The enamel is formed but once, and can not be replaced. While it is very hard, still, rough usage, such as cracking nuts with the teeth (instead of using a hammer), is likely to break off portions of it. The dentine, being exposed by the removal of the enamel, will begin to decay, and it is only a question of time before the loss of the whole tooth will follow, if steps are not taken to prevent it. Again, without fault of the owner, sometimes deposits of a substance commonly called "tartar" may form on the teeth, which may either irritate the gums or afford a place for the lodgment of particles of food, which, decaying at these points, may finally corrode the enamel and expose the dentine, with the above-mentioned results.

The proper use of the tooth-brush and tooth-picks would evidently help in this matter, to say nothing of their contribution to cleanliness, which good breeding demands. But with all the care that can be bestowed upon the teeth, cavities may begin to form and other troubles arise. A small cavity may form and grow to a considerable size before the owner of the tooth is aware of it. To anticipate all trouble, it is a good rule to have the teeth examined twice a year by

a competent dentist and put in order if necessary. The rule with the dentist is not to destroy a tooth by pulling if it is possible to save it by treatment, and this can generally be done if he can see it in time.

The Tongue.—The body of the tongue is made up of muscles whose fibers run in various directions. The inner extremity is chiefly fastened to the hyoid bone and to the front part of the sub-maxillary bone. Many of its muscles are wholly within the tongue.

The tongue is extended by the contraction of its transverse and vertical fibers, while the longitudinal fibers are relaxed. It is drawn back by reversing these actions. By various combinations of the actions of its muscles it may be moved in any number of directions. By coördinating its movements with those of the lips and cheeks, one is able to handle very skillfully any object in the mouth, even though it be a very small one.

The use of these movements is very obvious in presenting the food to the teeth and holding it between the proper ones during mastication, and in pushing it into the next passage in the act of swallowing. In addition to this function of the tongue, it is of great use in articulation and in carrying the organs of taste.

Glands of the Mouth.—The mucous coat of the mouth everywhere has imbedded in it numerous mucous glands. These are compound tubular glands. They secrete mucus in large quantities. Opening into the mouth are the ducts of the salivary glands.

Fig. 49.

SALIVARY GLAND.

Salivary Glands.—There are three pairs of salivary glands—the parotid, the sublingual, and the submaxillary.

The *parotid* gland, the largest of the three, is in the side of the face in the space behind the lower jaw and in

front of the ear. Its outlet is a duct which opens on the inner surface of the cheek near the second molar tooth.

The *sublingual* gland is the smallest, and is situated in the floor of the mouth just under the mucous membrane between the tongue and the gums. It opens by many ducts—eight to twenty in number.

The *submaxillary* gland is situated near the base of the submaxillary bone, opposite a small depression in the bone. It empties by a duct which reaches the mouth just under the free part of the tongue. The salivary glands are abundantly supplied with blood vessels and nerves.

The Pharynx.—The pharynx is an irregular cavity immediately following the mouth, separated from it by the soft palate. Its mucous lining is surrounded by muscular walls. It receives the openings of seven passages: one from the mouth, the two posterior openings of the nostrils, two passages to the middle ear (Eustachian tubes), one to the larynx, and one to the œsophagus or gullet—the continuation of the alimentary canal. Its muscular walls allow it to push the food into the œsophagus in swallowing, or to bring it up again from this point, if desired. The muscular fibers are mostly voluntary. The mucous coat is well furnished with mucous glands.

The Œsophagus or **gullet** is that part of the alimentary canal which connects the pharynx with the stomach. It is about nine inches in length, lying just along the spinal column in the neck and thoracic region. In the neck it is just behind the trachea (wind-pipe).

It has three coats—the inner or the mucous coat; an outer thick muscular coat; and a middle coat of loose connective tissue which holds these together. The muscular coat has an external layer of fibers running lengthwise, and an inner layer of circular fibers. The fibers are mostly involuntary.

The walls of the gullet contain great numbers of mucous glands.

The Stomach.—Just below the diaphragm in the abdominal cavity the alimentary canal dilates into a large pouch which we know as the stomach. The three coats of the œsophagus mentioned above are continued in the walls of the stomach: the *mucous coat*, the loose connective-tissue coat, called here the *submucous coat*, and the *muscular coat*. Outside of these is added a fourth, the peritoneum, which is the membrane that covers most of the organs in the abdominal cavity and lines the abdominal cavity itself.

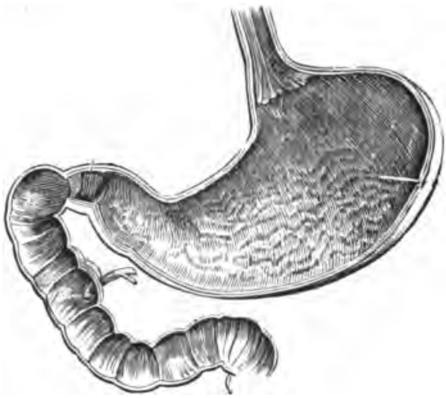


Fig. 50.

SECTION OF STOMACH AND DUODENUM.

The stomach is somewhat conical in shape, the larger end turned toward the left. Its size varies greatly, according to the amount of its contents. The opening from the œsophagus is called the *cardiac orifice;* the one leading to the intestine, the *pyloric orifice.*

Muscular Coat.—The muscular coat consists principally of a longitudinal and a circular layer of fibers, with a certain amount of oblique fibers. They are of the involuntary variety. At the pyloric orifice the circular fibers are greatly developed, forming a muscular ring, which can close the opening.

Gastric Glands.—The mucous coat of the stomach is crowded full of tubular glands, usually simple, but a few are

branched. These glands are microscopic, and of about the depth of the membrane, and vary somewhat in form and in the character of their secretion. The combined secretion of all is known as the *gastric juice*. A very close network of blood vessels encloses the glands; intermingled with these are both lymphatic vessels and nerve fibers, which are distributed to the cells of the surface of the stomach and the gland cells.

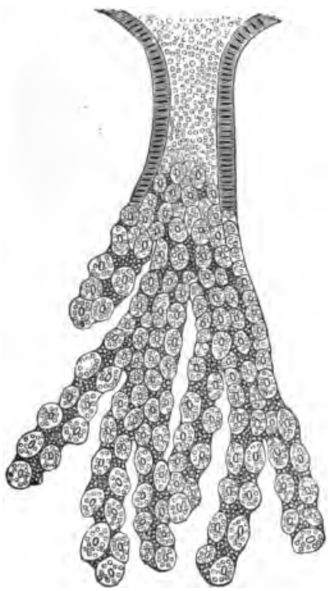


Fig. 51.

A Gastric Gland from the Pyloric End of the Stomach.

This shows only the lining cells without the blood vessels, etc.

The Small Intestine.—The stomach continues into the small intestine, a much smaller tube of about twenty feet in length. The coats of the stomach are continued in it, and in the same order. The outer coat, the peritoneum, does not completely surround it, but runs off from it to form the *mesentery*, a membrane which so supports this long tube that it does not become entangled in any of the motions of the body, while it lies loosely in the abdominal cavity.

The mesentery forms a long strip of membrane, the outer edge of which is the outer coat of the intestine, the inner edge being gathered up and attached to one place and supported by the spinal column. Through the mesentery the blood vessels and nerves reach the intestines, and by it the vessels used in absorption leave it.

Mucous Coat of the Intestine.—The mucous coat of

the small intestine differs from that of the stomach, first, in having the coat thrown into a great number of transverse folds, the *valvulæ conniventes;* second, in bearing on its surface an immense number of little projections, called *villi.* These are so peculiar and important in the processes of nutrition as to deserve special description.

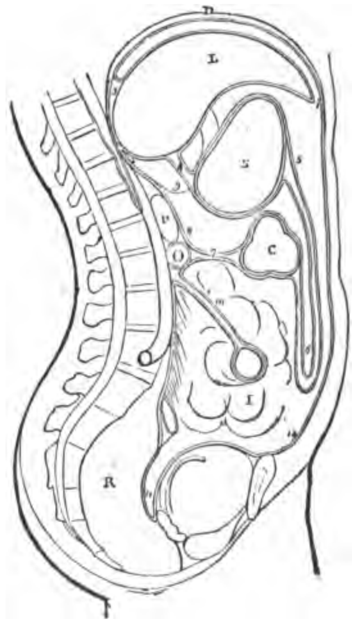


Fig. 51a.

SECTION OF THE ABDOMINAL CAVITY AND CONTAINED VISCERA, SHOWING THEIR POSITIONS AND THE REFLECTIONS OF THE PERITONEUM.

D, diaphragm; *S*, stomach: *C*, colon; *I*, small intestine; *B*, bladder; *R*, rectum; *P*, pancreas; *O*, duodenum. The numbers are placed on the peritoneum; 10 is the mesentery, and 6 the great omentum.

A *villus* is a minute projection from one fiftieth to one thirtieth of an inch in length, either conical or shaped like a finger of a glove (Fig. 52). Its outer coat consists of a single layer of epithelial cells resting on a base consisting of a delicate network of connective-tissue fibers. The core of the villus consists mainly of a network of blood capillaries, interlaced with another network of vessels like the lymphatics, really a part of the lymphatic system, called here the *lacteals.*

Besides these there are nerve fibers and a few muscle fibers, the whole being held together by a framework of connective tissue. A villus is essentially an absorbing organ, being a device to increase the surface and at the same time to bring the absorbing vessels very near the surface. The digested food passes through the thin outer coat into the blood vessels and into the lacteal vessels.

The *villi* are found only in the small intestine, whose walls are entirely covered with them.

Glands of the Small Intestine.—The mucous coat of the small intestine bears numerous glands. In the portion of the intestine immediately following the stomach, called the duodenum, is a small number of compound tubular glands, known as *Bruner's glands.* Throughout the whole

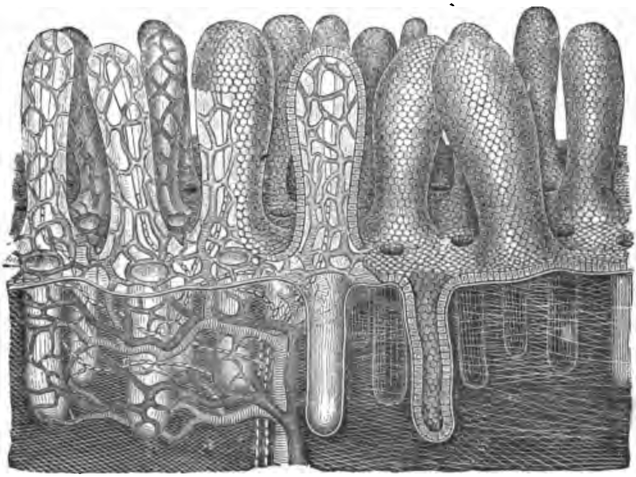


Fig. 52.

A SEMI-DIAGRAMMATIC VIEW OF A SECTION OF MUCOUS COAT OF THE SMALL INTESTINE, SHOWING VILLI WITH THEIR BLOOD VESSELS AND LYMPHATICS.

of the rest of the small intestine are immense numbers of simple tubular glands, packed closely together around the base of the villi. They are called the "crypts of Lieberkühn." Their secretion is poured into the intestinal tract, and is known as the *intestinal juice.*

The Liver.—At a distance of from three to four inches below the pyloric orifice, lying side by side, two tubes pour their contents into the small intestine. The one is the duct from the *liver*, the other the one from the *pancreas*.

The liver is the largest gland of the body, weighing from fifty to sixty ounces. It is just beneath the diaphragm, the largest part being on the right side; a thinner, broad extension covers a considerable portion of the stomach on the left side. It is held in place mainly by the membranes attaching it to the diaphragm. It is an immense compound gland, whose secreting cells pour their products, the *bile*, into a system of ducts whose parts finally join with one another and form the common bile duct whose opening has just been mentioned. Attached to the system of ducts is the gall bladder, which acts as a reservoir to retain the bile when it is not discharging into the intestine.

Blood Supply of the Liver.—The amount of blood that passes through the liver is very great, exceeding that of any other organ except the heart and the lungs. The supply is from the *portal vein* (see chapter on Circulation) and from the *hepatic artery*. As the portal vein gathers the blood from the spleen, the stomach, and the intestines, all the blood that passes through these organs must also pass through the liver. The blood passing through the portal vein has lost most of its oxygen at the organs just mentioned, and as the hepatic artery comes almost direct from the aorta, the liver cells get their oxygen through it.

These blood vessels, the hepatic artery and the portal vein, run side by side and divide and subdivide until they are distributed as capillaries surrounding the liver cells. These again join together to make a system of veins which ultimately empties into the inferior vena cava as the *hepatic* vein. This whole system of hepatic veins is imbedded in the substance of the liver.

The Pancreas.—The pancreas, the most important of the digestive glands, is a large gland of considerable size lying just behind the stomach against the posterior wall of the abdomen. It resembles in appearance and in minute structure a salivary gland. Its secretion, known as *pancreatic*

juice, is carried by the pancreatic duct into the small intestine which empties by the side of the bile duct.

The Large Intestine.—The large intestine consists of the *cæcum*, the *colon*, and the *rectum*. The cæcum forms a large sac into which the small intestine empties by a kind of valve, known as the *ileocæcal* valve. At the bottom, the cæcum extends into a very narrow projection called the *appendix vermiformis*, which in the human body has no function, being but a rudiment of what, in many of the lower animals, is a greatly developed cæcum, as seen in the rabbit or the horse.

The colon has an ascending portion, a transverse portion, and a descending portion, which terminates in the rectum. The coats of the large intestine are the same as those of the stomach and small intestine. The mucous coat has no villi, but has great numbers of the crypts of Lieberkühn.

Directions for Practical Work.

For the examination of the contents of the abdomen, any small animal will answer. A rabbit can generally be obtained, and for that reason is described below. The body is best handled when tied by the feet firmly to a board.

The ribs can be felt beneath the skin. The soft part below is the region of the abdomen. Slit open the skin along the middle line up to the breast-bone. Cut the skin through at right angles to the middle line. Separate it from the muscles and pin it to the board. The abdominal muscles are now exposed. Note the direction of the fibers.

Slit open the abdomen, pinning the muscular tissue back. This brings to view the parts of the internal organs. See each one in its natural position. The apron-like covering is the *great omentum*.

The thoracic cavity (not yet opened) is bounded in front by the ribs and separated from the abdominal cavity by a muscular partition, the *diaphragm*, which can now be seen. Near it and suspended from it is a large, dark-red gland, the *liver*. Immediately below it, and to the left, and partially covered by it, is the *stomach*. The part of the alimentary canal following this is the *duodenum;* and in a loop which it makes lies the *pancreas*. The large dark vessel which is most conspicuous on open-

ing the abdomen is the *cæcum*. Care must be taken not to open it. The *colon*, with its three rows of pouches, lies between its folds. The last part, the *rectum*, may be seen at the posterior end of the colon.

Now study the separate organs, laying the parts about as may be necessary.

The liver consists of several lobes. The *gall bladder* is on the under side. Note the shape of the stomach and its two openings, one for the œsophagus, and one for the duodenum. The *spleen* is a small, dark-red organ attached to the stomach. Now trace the full course of the intestines through all their windings. This will show how completely the mesentery holds all the parts in place. In it will be found many blood vessels. The lining of the walls of the abdominal cavity is the *peritoneum*. It is reflected off upon the mesentery, and covers the stomach, liver, and intestines.

Open the thoracic cavity and find the œsophagus. Make a ligature around it, and likewise one around the rectum. Remove the whole alimentary canal to a pan with sufficient water to float the parts, so that they may be put easily into any desired position. The mesentery, as well as other parts, may be studied to advantage.

Find the kidneys, one on each side of the spinal column, in the back part of the abdominal cavity.

The tubes running from these to the bladder are the *ureters*.

Slit open different portions of the alimentary canal, wash out its contents. Note the different coats. Note the degree of smoothness of the internal surface in the different organs.

If a rabbit is not to be had, a frog, or a cat, or a rat, or a chicken may be used.

The Thorax.—As in a subsequent chapter the thorax is to be studied, it should be examined before this animal is thrown away. The practical directions for the examination will be found at the close of that chapter.

Review Questions.

1. In what does digestion consist?
2. What renders the process necessary?
3. What constitutes the digestive system?
4. What is the distribution of the mucous membrane?
5. What is the function of the digestive glands?
6. What is the plan of a gland?

7. Of what form is the simplest gland?
8. Give examples of such secreting surfaces.
9. What is a simple tubular gland?
10. What is a compound gland?
11. Describe its structure, and illustrate it with a diagram.
12. How does a gland illustrate the principle of the division of labor?
13. What relation do the glands have to the lining surface of the alimentary canal?
14. What is the cause of the activity of the gland cells?
15. How is their secretion controlled?
16. Describe the mouth.
17. Of what does the mucous layer consist?
18. What is a papilla?
19. What kind of papillæ are found in the lips?
20. What kinds on the tongue?
21. Describe each.
22. In what sets do the teeth occur?
23. What is the time and order of their occurrence?
24. How are the teeth named?
25. Give the dental formula for man.
26. How do the teeth of some of the common animals differ from those of man?
27. Give the structure of a tooth. Illustrate with a diagram.
28. What differences exist in the materials of a tooth?
29. How is the nutrition of a tooth supplied?
30. How is the tooth held in place?
31. What are the uses of the teeth?
32. What is said in regard to the care of the teeth?
33. Give the structure of the tongue.
34. How is it extended, and how drawn in?
35. What are its functions?
36. What are the glands of the mouth?
37. Give the positions of the salivary glands.

38. How does each open into the mouth?

39. Give the location of the pharynx.

40. What passages open into it?

41. Describe the stomach, giving its position, size, and form.

42. What of its muscular coat?

43. Give a description of the gastric gland.

44. What of the number of these glands?

45. What is their secretion?

46. Give the location and attachments of the small intestine.

47. What are its coats?

48. Describe the mesentery.

49. Describe in detail a villus.

50. What is its function?

51. What vessels carry away the dissolved food, and how does it reach them?

52. What are the glands of the small intestine, and where are they placed?

53. Describe the liver, giving its form, size, attachment, and position.

54. What is its structure?

55. How are the secretions carried away, and at what point do they empty?

56. What is bile?

57. Give the uses of the bile.

58. What is said of its digestive action?

59. Through what vessels is the blood supplied to the liver?

60. How are they distributed to the liver?

61. How does the liver get its oxygen?

62. Where is the pancreas, and at what point does it pour its secretion into the alimentary canal?

63. Describe the large intestine.

CHAPTER XI.

THE PHYSIOLOGY OF THE DIGESTIVE SYSTEM.

Functions of the Secretions in the Alimentary Canal.—From the preceding sections we have seen that the secretions which enter the alimentary canal are:

The mucus, secreted throughout its whole extent;
The saliva, poured in at the mouth;
The gastric juice, secreted from the walls of the stomach;
The bile, poured into the small intestine;
The pancreatic juice, poured into the small intestine; and
The intestinal juice, into the small and large intestine from their thin walls.

Not all of these liquids are digestive in action—that is, have the power to render any of the insoluble food substances soluble. Some may have other functions as well.

Uses of Saliva:

1. Its most important use is to moisten the food so that it may be swallowed.
2. Its next most important use is to allow substances to be tasted, since dry substances can not reach the organs of taste until they are dissolved.
3. It, together with the mucus, keeps the lining of the mouth and pharynx in a suitable condition for the easy movements of their parts in speaking.
4. The saliva also may exert an important digestive action on starches. When kept with starch at the temperature of the body it will change it into sugar. This change is effected by a substance called *ptyaline*, which exists in small amount in the saliva. This

action on the starch is made more rapid if the starch has been cooked.

The starch-digesting power of the saliva is stopped by the presence of the acid of the gastric juice in the stomach, which in a short time destroys this power altogether. Hence, the ptyaline is actively applied to the food but a very short time, and can not be a very great factor as a digestive agent. The saliva makes no changes in the proteids or fats.

Gastric Juice.—The name gastric juice is applied to the mixed secretion of the glands lining the stomach, which differs somewhat in its characteristics when taken from the glands in different regions of the stomach. The whole solution has a marked digestive action on the proteids, which consists in changing the insoluble proteids given in the list of food substances (*q. v.*) into a soluble group of proteids called *peptones*.

The gastric juice also has the power to curdle milk. The first action is due to a digestive substance called *pepsin*, the second action to another substance called *rennin*. Both these substances exist in very small amounts in the gastric juice, and act only in the presence of an acid. The acid of the gastric juice is hydrochloric acid, which exists in it in but small amount. Gastric juice has no action on starches or fats.

Pancreatic Juice.— Pancreatic juice rapidly changes starch into sugar.

It changes proteids into peptones.

It has two distinct actions on fats; one is to emulsify them—that is, to reduce them to a very finely divided state, so that the minute particles may pass through the cell lining of the intestine; the other is to decompose them into two soluble substances called glycerine and the fatty acids. Pancreatic juice will act only in an alkaline liquid.

It will thus be seen that the pancreatic juice is the most important of the digestive liquids, acting with energy on each of the organic food groups.

The Bile.—The bile is a very complex liquid, a part of it being excretions to be gotten rid of, a part of it being a true secretion to be made use of in the body. The *digestive action* of the bile is feeble. It emulsifies the fats to a small extent. It has little if any action on starches or proteids.

While it has such unimportant digestive actions itself, yet it is a valuable aid in certain digestive processes performed by other parts.

1. It has been found that it puts the epithelial lining of the intestine in a better condition to absorb the fats.
2. It acts as a stimulus to the muscular coating of the intestine.
3. It makes the contents of the small intestine alkaline, thus bringing about the necessary condition for the action of the pancreatic juice.
4. It furnishes a large bulk of liquid, so that the contents of the intestine may be moved along readily.
5. It is probably an antiseptic—that is, retards the putrefactive changes the foods would otherwise undergo in the intestine.

Intestinal Juice.—Great difficulties have been in the way of obtaining this liquid free from other liquids for the purpose of investigation. Yet it is believed to have a very slight digestive action on each of the food groups, but not vigorous enough to be of any importance in this direction. If it has any other functions they are not known.

Bacteria in the Intestine.—Immense numbers of these minute organisms thrive in the contents of the alimentary canal. Evidently they are usually of kinds that are perfectly harmless. Indeed, it is thought by some physiologists that some of them produce important digestive changes in the foods. We have no cause to be alarmed at their presence. As scientists have not been able to decide whether they are plants or animals, we may regard them as plants in this position if it best suits our feelings about the matter.

For further information in regard to bacteria see Chapter XXII.

Movements of the Alimentary Canal.—After the food is masticated by the motions of the jaws, lips, cheeks, and tongue, it is gathered on the upper surface of the tongue. The front part of the tongue is pressed against the roof of the mouth, and by a quick motion the mass is thrown into the pharynx. In this cavity it is immediately seized by the muscular walls, first the upper and then the lower portions, and pushed with considerable rapidity into the œsophagus, the larynx in the meantime closing by an apparatus called the epiglottis, to be described in another chapter.

In the *gullet* the circular fibers just before the mass relax, and the ones just behind it contract and push it along very quickly into the stomach. Liquids and solids receive the same treatment.

In the *stomach* the fibers of the different coats so contract in successive turns as to move the mass of food along one side, back along the other, and in various directions, so that it is completely mixed with the secretion. The muscular ring at the pylorus remains most of the time closed, allowing during such a time only liquid portions of food or fine particles to pass. At certain times, however, portions of considerable size may be allowed to pass it.

In the small intestine the two muscular coats, by constant slow motions, pass its contents along to the large intestine, where the motions are somewhat the same. The movements of the stomach and intestines are known as *peristaltic motions.*

Nervous Control.—Nerves leave the surface of the alimentary canal at every point to go to nerve centers (see Nervous System), to bring sensory impulses from it to the centers. From these centers nerves go out again to the coats of the canal—one set to the muscles to control their motions, another set to the blood vessels to control the sup-

ply of blood in its various regions, another set still to the gland cells to control their secretions.

By this means the food and other things affecting the surface of the canal are made to regulate the flow of blood and the making of the secretions to meet the needs of the time and place.

By this nervous apparatus the presence of the food in the mouth excites the secretion and flow of the saliva; in the œsophagus, the movements of swallowing; in the stomach and intestines, the various actions of muscles, glands, and blood vessels as it reaches their regions. These are involuntary actions, except for the muscles of the mouth and the pharynx.

Comparison of the Alimentary Canals of Different Animals.—The preceding sections, which are but a brief survey of the alimentary canal of the human body and the functions of its parts, show it to be a very complex system, consisting of many different parts, with many different glands furnishing many different kinds of secretions.

In the comparative study of the digestive tracts of animals it is possible to arrange a series, from one-celled animals, whose single cell accomplishes all this work, ascending next to one whose digestive apparatus is a single cavity lined with a single layer of cells all alike, by another step to one with a little more complexly formed tube, and so on, the cells gradually dividing up the work, until at last the very complicated system as shown in man is reached. In some of the higher animals the alimentary canal is even more complex than in man, as in the sheep or cow.

The alimentary canal in each animal must be adapted to the kind of food on which it subsists. It is a very interesting study to trace in the common animals around us the way in which these adaptations are carried out. Of course, to have the most perfect examples we should take those in a wild state, as in the domestic state, with a lower animal, as with

man in a civilized state, the necessity of some of the organs is not so imperative.

Different kinds of fishes, birds, reptiles, and mammals would well repay even a superficial examination in respect to their foods and the methods by which they take the different kinds of food, and the organs by which they pass it through one process after another until digested.

Absorption.—The food having been digested, the next process it undergoes is that of *absorption.* As long as the food is inside the alimentary canal it is not yet, properly speaking, in the body. It has not yet passed through any of the outlying cells of the body. It can now be traced into the blood. It gets into the blood by two ways:

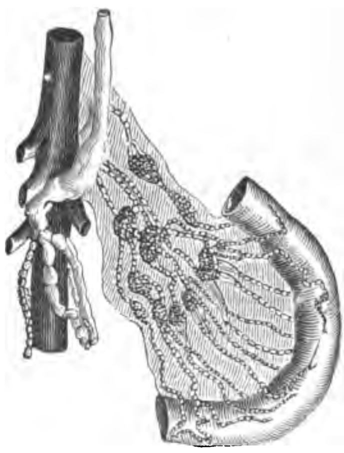


Fig. 53.

A PORTION OF THE SMALL INTESTINE ATTACHED TO THE MESENTERY, IN WHICH ARE SHOWN THE LACTEALS RUNNING THROUGH THE GLANDS TO THE THORACIC DUCT.

First, it may pass through the epithelial lining either of the stomach or of the intestines, and then through the walls of the blood capillaries, which are abundantly distributed even to the very surface of the walls of these organs, and in the core of the villi in the small intestine, and thus into the blood at once. In this case the digested food mingles with the blood, and is carried along with it through the gastric or mesenteric vein, as the case may be, into the portal veins, through the liver, into the hepatic vein, into the vena cava ascending, and then to the heart.

Second, in the stomach; instead of passing to the blood

capillaries, it may pass into the lymphatic capillaries, and in the small intestine may pass into the lacteals, which arise in the core of the villi by the side of the blood capillaries. These run together to form larger and larger vessels in the mesentery, until they finally, with the lymphatics from the stomach and from the other parts of the body, empty into the thoracic duct. The thoracic duct empties into the left subclavian vein (see Fig. 53). Here its contents are mingled with the blood which soon comes to the right auricle by the vena cava ascending. Consult in this connection the diagram given to show the course of the blood in circulation.

Where the Different Kinds of Foods are Absorbed.— Whatever is already a liquid or in solution in water may be absorbed from the stomach. This may be water, peptones, sugar, or salines. No doubt a considerable amount of these substances are taken up here.

But by far the greater amount of the absorption takes place from the small intestine. The great length of the passage, the valvulæ conniventes, and the immense number of villi, all unite to make this region preeminently an absorbing one.

The peptones, the digested proteids, the sugars, and the salines are taken up by the blood vessels. These same substances are also taken up to a certain extent by the lacteals, but it is only by these last that the emulsified fats are taken up at all.

The emulsified fats which crowd these vessels and the thoracic duct after a meal in which fats and oils have been taken with the food give them a white color, as if they were filled with milk. Absorption of peptones and sugars can also occur in the large intestine.

The indigestible food substances taken with the foods are separated from them and left behind, to be pushed along the canal, and are accumulated in the large intestine, to be removed from the body.

The Glycogen-producing Function of the Liver.—In this connection we may mention the power the liver has of producing a substance called *glycogen.* Glycogen is much like starch in its chemical composition, and is sometimes termed animal starch. It is thus a carbohydrate. It is soluble in water. It is retained in the liver cells, or discharged by them directly into the blood without making use of any ducts. It is probably a storage material, or an antecedent of one.

Thus we see the liver has already many known functions: the formation of the bile, which is in part an excretion and in part a secretion, with several uses, and the formation of glycogen. No doubt there are other uses of the liver cells to be solved by future investigation.

The Spleen.—The functions of the spleen are not definitely known. Consequently, it is not to be regarded as a digestive organ, but since it is associated with them, its description may be given here.

It is a soft body of grayish purple color, located on the left side of the abdominal cavity, between the cardiac end of the stomach and the diaphragm. It is abundantly supplied with blood by the splenic artery, its blood leaving it by the splenic vein, which flows into the portal vein. Its vessels are very numerous and allow it to become very much distended by the blood. It has no duct, and is not of the structure of a typical gland.

The Suprarenal Bodies.—These are two small bodies, one being attached to the upper part of each kidney. They are well supplied with blood, but have no duct. Their functions are not known.

Effects of Alcohol on the Digestive Organs and Processes.—Effects of Alcohol on the Stomach.—The effects of strong alcohol on the walls of the stomach are to kill the living cells of its tissues, and to coagulate the proteid contents of these cells. This, of course, destroys the

walls, and would produce death. But taken in small amounts it has but little apparent effect. Long-continued use, however, may interfere with the secretion of the gastric juice. It is known that many alcoholic drinks retard digestion. It is certain that many people suffer serious derangement of the digestive processes by the continued use of these drinks. Excessive use produces very serious results. Alcohol is not digested in the alimentary canal, but is absorbed as alcohol from it by the blood vessels, and as such reaches all the other organs, on which it acts directly.

Alcoholic Drinks and the Liver.—We have seen that the liver is the largest gland in the body, and that its work is very important; and there is reason to believe that its influence on the general nutrition of the body is even greater than is indicated by the functions which have been determined as belonging to it. Now we have also seen that all the blood that passes through the stomach and intestines next passes through the liver. Thus the alcohol which is absorbed from these organs (most of it probably from the stomach) immediately passes to the liver. As a result, the liver is greatly affected. The presence of alcohol in this organ interferes with the action of both the secreting cells and with its blood vessels. These changes disturb the normal functions of the liver. Continued use of alcoholic drinks may produce permanent changes in its structure. There are a number of serious diseases of the liver that are directly traceable to the effects of alcohol on this organ. Naturally, when so large and important an organ is disturbed, the body as a whole is much influenced, and many maladies have their origin in a liver thus affected. (For full discussion of alcohol on the system see Chapter XXII., pp. 288–294.)

Review Questions.

1. Name the secretions of the alimentary canal and the points at which they occur.

2. What are the uses of the saliva?
3. Which is the most important use?
4. In what manner does it act as a digestive agent?
5. What is the gastric juice?
6. What are its digestive principles?
7. What is the action of the gastric juice?
8. What are the digestive actions of the pancreatic juice?
9. Why is it stated to be the most important digestive liquid?
10. What is the bile?
11. What are its digestive actions?
12. What are its other functions?
13. What is the intestinal juice, and what are its functions?
14. What is said of the bacteria in the alimentary canal?
15. Describe the process of mastication.
16. How is the food swallowed?
17. What are the motions of the stomach?
18. How are the contents of the intestine moved along?
19. How is the alimentary canal connected with the nerve centers?
20. How are the motions and secretions controlled?
21. How is digestion accomplished in one-celled animals?
22. What is said of the series between the simplest digestive apparatus and the most complex?
23. Why are the digestive systems among animals so diverse?
24. What is the process of absorption, and on what does it depend?
25. What are the absorbing vessels?
26. How does the digested food get into each?
27. What is the course from the intestines to the heart of the part of the food absorbed by the blood vessels?
28. What is the course of that absorbed by the lacteals?
29. What may be absorbed from the stomach? What from the small intestine? What from the large intestine?

30. What is glycogen ?
31. Where is it produced and what are its functions ?
32. What is meant by a " storage material " ?
33. Describe the spleen and give its position.
34. What is said of its function ?
35. What are the suprarenal bodies ?

CHAPTER XII.

THE RESPIRATORY APPARATUS.

Definition.—The most obvious fact of respiration is the bringing of the air into the lungs and expelling it again. In ordinary language, by the term respiration these two acts are meant.

It may be recalled that every living cell demands two things—food and the gas oxygen; and that in its activity these combine in such a way that certain waste products are produced, one of which is always the gas carbon dioxide. It has been seen that in the single-celled animals, or in those of comparatively few cells, the supply of both food and oxygen, coming into direct contact with them, passes into their substance. The waste products, among them carbon dioxide, pass immediately from them into the surrounding medium, water or air. In these single-celled forms, the taking in of oxygen and the discharge of the carbon dioxide is respiration.

It was further shown that in animals of large size with many tissues the great majority of the living cells of the tissues were buried deep away from the external surface. But even in this inaccessible position, living cells have the same requirements as elsewhere. The cells in the tissues get their supplies of nutrition and oxygen from the blood, and discharge their wastes into the same liquid, the blood being the medium in which they live.

Now, the acts of taking in oxygen and discharging carbon dioxide by the cells in the tissues is true respiration. This act of the cells has been called *internal respiration*, to distin-

guish it from the action of the respiratory organs, the *external respiration.*

General View.—Just as the digestive organs form a device to prepare the food for the blood to be carried to the tissue cells, so the organs of respiration form a contrivance to present oxygen to the blood for the cells and remove the carbon dioxide which they have thrown off.

In the different animals the respiratory apparatus differs considerably, but in the majority of cases it consists of a device for exposing a great amount of thin-walled tissue, which is a modification of the outer coat of the animal, to the air or water; and further consists of a means to keep up a current of air or water on the outside of the skin and a current of blood on the inside. This arrangement provides for as great an exchange of the two gases, oxygen and carbon dioxide, between the blood on the one side and the air or water on the other side, as may be needed for the activity of the animal.

In the common earthworm the whole outside skin is such a surface. In insects the sides of the body have many small openings (spiracles) which lead to minute tubes penetrating every part of the body. By motions of the body the air is made to flow through these spiracles and tubes. In fishes the well-known gills accomplish the same purpose. In frogs the lungs consist of two simple sacs at the end of a tube, which is a branch of the alimentary canal. The animal swallows the air into the lungs. Its thin, moist skin is also an organ of respiration.

Turtles, also, make use of lungs, but the inner surface of their lungs is greatly increased by many divisions of the sacs. In birds the lungs are very much more complex, presenting an immense amount of surface to the air. They have also a special muscular apparatus for allowing the air to come into and forcing it out of the lungs.

In man and other mammals the lungs are still more highly developed. It has been estimated that by the continually

finer and finer division of the great air sacs, a pair of human lungs presents a surface of sixty square feet to the air. The diaphragm and other special muscles cause quite a rapid change of the air to and from this immense surface.

The Respiratory Apparatus.—In the human body the

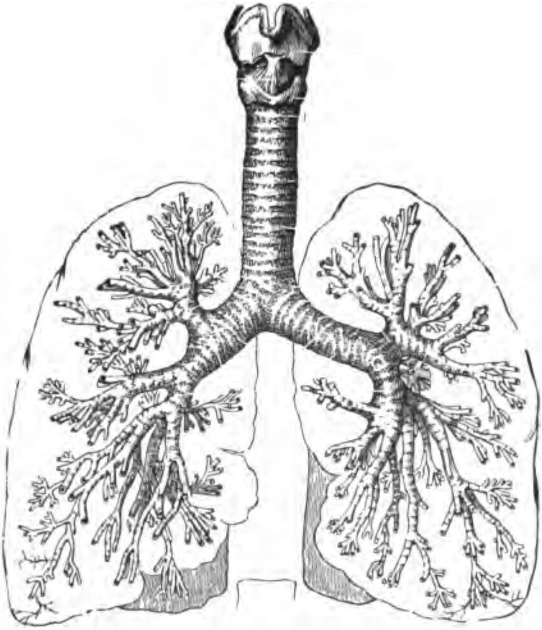


Fig. 54.

LARYNX, TRACHEA, BRONCHI, AND BRONCHIAL TUBES.

respiratory apparatus consists of a series of passages traversed by the air, which terminate in two very complex sacs, projecting freely into the cavity of the thorax. The passages traversed by the air, in order from without to the lungs, are: *nostrils* and *mouth*, *pharynx*, *larynx*, *trachea*, *bronchi*, *bronchial tubes*, *finer air passages*, and, last of all, the *air vesicles*. These ultimate divisions of the air passages are

minute sacs clustered around the last divisions of the air tubes. They exactly correspond to the last divisions of a gland. Indeed, the lungs are to be regarded as large glands, in which the cells of the minute air sacs take the place of the secreting cells.

These air sacs, or *vesicles*, as they are called, are about one hundredth of an inch in diameter. Each is composed of a lining of very flat, thin cells, resting on a delicate, connective-tissue support which is very elastic. Immediately next to this support, and very close to the lining cells, is a close network of capillary blood vessels. These capillaries bridge over the space between the pulmonary arteries and the pulmonary veins. Each air vesicle is well enveloped by a network of blood vessels, and in many places they so crowd on one another that a network of blood vessels may have an air vesicle on each side of it (Fig. 55).

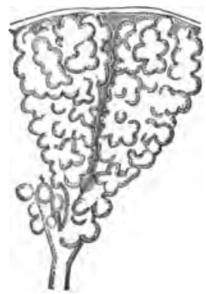


Fig. 55.

A GROUP OF AIR VESICLES AT THE END OF A BRONCHIOLE.

Function of the Air Vesicle.—The air vesicle is an arrangement to bring the blood as close to the air as possible. In it the blood is separated from the air only by exceedingly thin membranes, which allow the very ready passage of carbon dioxide, oxygen, and the vapor of water.

The Bronchioles.—The air vesicles, or alveoli, are clustered together, and opening into a common passage, soon form the smallest definite tubes in the lungs, called the *bronchioles*, the smallest *bronchi*, or smallest bronchial tubes.

The Bronchial Tubes.—The bronchioles run together, making larger and larger tubes (Fig. 54). All those of one lung empty into one large tube. This large tube is called a *bronchus*; the smaller divisions, the *bronchial tubes*.

The Trachea and Larynx.—The two bronchi, one from

each lung, unite to form the trachea or windpipe. This is a large tube in the neck, easily located under the skin. It lies just in front of the œsophagus. On the top of the trachea is fixed the larynx, the organ of voice, a passage connecting the trachea with the pharynx.

Structure of the Trachea and Bronchi.—The trachea, and its two branches, the bronchi, are the same in structure. In the trachea the walls of the tube are supported by a series of C-shaped rings, the opening of the C being turned toward the œsophagus. In the bronchi the rings are continued, and they are found in all the smaller divisions of the bronchi as far as the bronchioles. These cartilaginous rings thus form an elastic framework, which supports the other parts, and are for the obvious purpose of keeping the passage freely open.

The rings are held in place by strong connective tissue, in which they may be considered imbedded. Resting upon the rings and connective tissue are the other layers of the mucous lining of the trachea, bronchi, and air passages. This consists, first of all, on the inner surface, of a layer of ciliated epithelial cells.

These form a layer of closely packed columnar cells, the free ends of which are covered with a number of very fine projections like the hairs on a brush (Fig. 56). During life these keep up a vibrating motion, rapid and strong toward the pharynx, slow and feeble toward the bottom of the lungs. The effect of the combined action of all these fields of waving cilia, which the whole lining of the air passages presents, is to drive out the mucus, of which there is an abundance, along with particles of dust, brought in by the air, which may adhere to it. By this means the air passages are swept clean of what in time would surely close them.

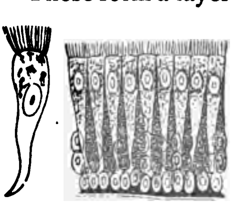


Fig. 56.

Ciliated Epithelium from the Lining of the Trachea.

Blood Supply to the Lungs.—As we have seen in the chapter on Circulation, the pulmonary artery leaves the right ventricle. It soon divides into two large branches, each turning toward one of the lungs. These subdivide, and an artery follows each bronchial tube down into the substance of the lungs, the minutest divisions ending in the capillaries which surround the air vesicles, as we have seen.

From the capillaries the blood is gathered into the veins, which run back toward the heart, side by side with the arteries and air passages, until near the heart, where they empty by two pairs of veins, one on each side of the left auricle. The lungs also receive a supply of blood from the arteries of the systemic system, whose subdivisions are distributed to the trachea, bronchi, air tubes, and to the substance of the lung itself.

Pleura.—The lungs are suspended in the thorax; they are covered with a membrane of connective tissue called the *pleura*. This is a very elastic membrane of connective tissue. It is reflected from the lungs to the sides of the thorax, over the diaphragm, and up to the lungs again. The portion of the pleura on the lungs lies against the pleura on the walls of the chest. Between them is secreted a liquid which reduces their friction to a minimum.

A thin partition divides the right half of the thorax from the left, thus providing each lung with a separate chamber. The arrangement of the pleura causes each lung to hang in a cavity which has no connection, except by microscopic pores, with any other. Of course, it is air-tight. The heart being above the diaphragm, the lungs are shaped to fit over it.

The Thorax.—The cavity called the thorax is the upper part of the body cavity partitioned off from the other portion, the abdomen, by the diaphragm. Thus the diaphragm forms the floor of the thorax. The diaphragm is a dome-shaped sheet of muscle, convex upward. Its rim is attached to the

body walls; its central portion thins away and has its muscular part replaced by a sheet of connective tissue called the *central tendon* of the *diaphragm.*

The diaphragm is held in its dome-shaped form by the contents of the abdominal cavity below pressing up against it. It is supplied with a pair of large nerves, the *phrenic nerves,* through which it receives the impulses that throw it into action. The diaphragm is pierced by the œsophagus, the aorta, and the vena cava ascending. The walls of the thorax form a cone (Fig. 57). These walls are supported behind by the dorsal vertebræ, by the ribs at the sides, and in front by the ribs, their cartilages, and the sternum.

Fig. 57.

THE FRAMEWORK OF THE THORAX.

Respiratory Muscles of the Thorax.—A very large number of muscles may be brought into action in forced breathing. The principal ones in ordinary respiration are those which move the ribs, including a group of muscles running from the posterior portion of the ribs to the vertebræ above, called the *elevators* of the *ribs;* the oblique bands of muscles in two sets between the ribs, the *intercostal muscles,* external and internal, and certain muscles of the back, the neck, and the head. Besides these, connected with the chest, the abdominal muscles, located in the front and lateral walls of the abdomen, are extremely important.

Inspiration.—That portion of the act of respiration which is occupied in bringing the air into the lungs is called inspiration. This is the enlarging of the cavity of the chest. If

the thoracic cavity is enlarged, the pressure of the air transmitted to the lungs through the air passages will expand the elastic walls of the lungs to follow the retreating walls of the thorax. It is the pressure of the air which expands the lungs, and not the expansion of the lungs which "draws the air" into them. The pulling away of the walls of the thorax from their surface takes away the support to this pressure of the air, which is about fifteen pounds to the square inch, and allows it to expand them and thus fill them, which is the object of the whole action.

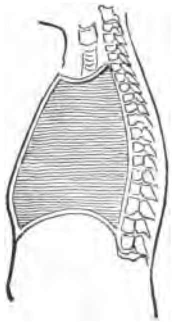


Fig. 58.

SECTION OF THORAX IN INSPIRATION.

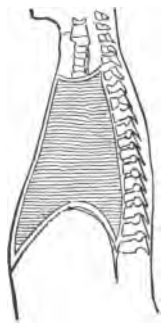


Fig. 59.

SECTION OF THORAX IN EXPIRATION.

Enlargement of the Thorax.—The thorax is enlarged in two ways:

1st. By the contraction of the diaphragm. The diaphragm being arched upward, in contracting tends to straighten, pushing the contents of the abdominal cavity before it, and thus it pulls away from the lungs by lowering the floor of the thorax. The lungs follow it closely.

2d. By the action mainly of the elevators of the ribs and the external intercostal muscles. The ribs, being rigid bars curved downward and outward, and at-

tached at each end to solid supports, will plainly be thrown outward when they are elevated by this action.

While it is easy to understand how muscles attached to the ribs and to the vertebræ above them can, by contracting, lift them, it is not so plain how muscles between them may, by contracting, do the same. But it can be made clear by studying the effect of shortening first the line *BC*, then the line *AD*, in Fig. 60, representing a framework of two rigid rods, *AB* and *CD*, held apart by two others, *AC* and *BD*, making a parallelogram, the corners having pivots allowing free motion. If the figure is held so that *BD* is vertical, *B* being uppermost, then shortening *BC* will elevate the rods *AB* and *CD;* shortening *AD* will depress them. The action of the external intercostal muscles is the shortening of *BC*, while the action of the internal intercostals is the shortening of *AD*.

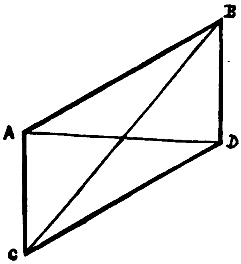


Fig. 60.

DIAGRAM TO SHOW THE ACTION OF THE INTERCOSTAL MUSCLES.

The above description applies to an ordinary inspiration, but if one will observe his own action during a forced inspiration he will see that the muscles of the shoulders, breast, neck, larynx, pharynx, and face are brought into action.

Expiration.—In expiration the floor of the chest, the diaphragm, is elevated, while the walls are brought nearer together by depressing the ribs. The diaphragm being but a flexible sheet, while it can depress itself by shortening, evidently can not elevate itself by relaxing. It is forcibly pushed up by the contraction of the muscles in the walls of the abdomen, thus pressing on the contents of the abdomen, which can not give way in any other direction so readily as in that of the diaphragm. The ribs are depressed in ordinary respiration by the weight of the chest and the pull of the

walls of the abdomen below, and by the elasticity of the cartilages which unite the ribs to the sternum. When the ribs are elevated these cartilages are slightly twisted, and their elasticity tends to throw the ribs down again.

During forcible expiration the internal intercostals contract—*AD* in Fig. 60—and thus depress the ribs. Other muscles of the trunk may be brought into play. But even in forcible expiration the main force relied on is the contraction of the abdominal muscles, the effect of which, in elevating the diaphragm, is increased by throwing the body forward.

Brief Statement of the Respiratory Movements.—In ordinary breathing, the diaphragm, contracting, lowers the floor of the thoracic cavity; the external intercostals raise the ribs and extend its walls. The pressure of the air drives the walls of the lungs after these retreating walls, thus increasing the amount of air in the lungs. These acts constitute *inspiration.*

Immediately following this, the abdominal muscles contract and force the contents of the abdomen against the diaphragm, which elevates it against the lungs. The cartilages of the ribs, together with the weight of the ribs and the other things attached to them, depress them, which action compresses the lungs. This is *expiration.*

In forcible breathing many other muscles aid in these two movements.

Nervous Control of the Respiratory Apparatus.—*Nerves of Respiration.*—Nerves are distributed to the mucous lining of the whole of the air passages which connect them with the medulla oblongata, a part of the brain. Other nerves go to the muscles of the larynx. The phrenic nerve passes from the spinal cord to the muscular fibers of the diaphragm. One set of nerves goes to the external intercostals, another set to the internal intercostals, another set to the abdominal muscles, all from the spinal cord, which connect the nerves with the medulla. The medulla, by means

of nerve fibers, is also connected with the remainder of the body. (*See Nervous System.*) That portion of the medulla to which fibers from the lungs come is called the ***respiratory center.*** It is the point from which the nervous impulses are sent out that make the respiratory muscles contract.

This nervous center is usually stimulated by the blood that circulates through it. If the blood has a small amount of oxygen, the effect on the nerve-center in the medulla is to cause it to send out impulses which increase the respiratory acts. If it contains a great amount of oxygen, the stimuli are less in strength.

Thus it comes about that relative amounts of carbon dioxide and oxygen in the blood fresh from the lungs is the means of regulating the machinery which has for its object the exchange of these gases of the blood. If from any cause the oxygen supply is cut off—for example, by choking—the blood passing through the respiratory center is not oxygenated. It in consequence causes more and more powerful stimuli to be sent out, until every muscle in any way connected with the action of respiration is brought into play, even very forcibly, producing gasping, strangling, and other convulsive movements whose purpose is to increase respiration.

The respiratory center may also be thrown into action by stimuli which come to it from the lining of some part of the air passages. For example, if a small object is lodged in the larynx, it stimulates the endings of the nerves in the mucous lining of that organ. The nerve (Fig. 61) carries the impulses to the center and causes it to send out the impulses that go to the muscles which produce a cough.

Stimuli from other sources coming to the respiratory center, such as a draught of cold air on the skin, may produce a sneeze.

Stimuli arising from the upper part of the brain will produce either sighing, crying, or laughing—all respiratory acts.

Impulses from the other parts of the brain, sent to the respiratory center as voluntary impulses, make it act under the direction of the will, as in talking or singing.

The respiratory center is thus a very delicately adjusted one, influenced by even slight changes in any other part of the body. Through it the complicated respiratory mechanisms are constantly nicely adjusted to the ever changing conditions of the body. It is one of the most important nervous centers. An injury to it suddenly stops the respiratory action, causing immediate death.

Explanation of the Diagram in Fig. 61.—The trachea and lungs are shown in outline. To the right is the outline of the brain and spinal cord, showing the respiratory center in the medulla oblongata.

The lines connecting this with the respiratory apparatus represent the nerves, on which arrows are placed to show the direction of the nervous impulses. Some go to the center, some come from the center to the muscles of the larynx, to the diaphragm *D*, to the abdominal muscles *AB*, and others to the intercostal muscles, *Int.* A study of the diagram in connection with the preceding sections will make clearer the method of the nervous control of the respiratory apparatus.

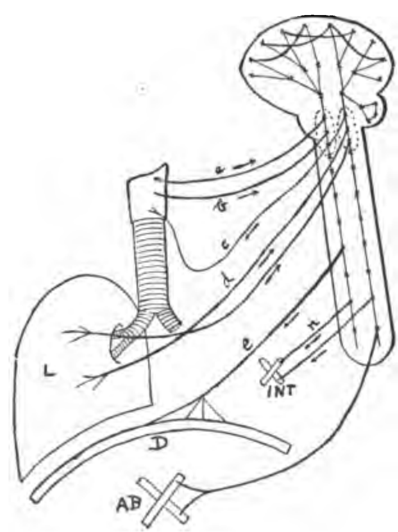


Fig. 61.

DIAGRAM TO SHOW THE NERVOUS CONTROL OF THE RESPIRATORY APPARATUS.

The explanation is given in the text. Modified from Landois and Sterling.

Number of Respirations.—The rate of the respirations in man is about eighteen per minute in the adult. The number varies with the age, those of a child less than a year old being about forty-four per minute; from fifteen to twenty years about twenty per minute. The rate varies much also with the activity of the body. In different animals the rate varies greatly, from once a minute in the hippopotamus, to two hundred and ten per minute in the rat. The student may easily study the different rates under the various conditions of the human body, and in many of the common animals.

Directions for Practical Work.

The thorax of a rabbit will answer well for examination. First remove the skin and examine the arrangement of the ribs, the cartilages, and the sternum.

Note how the intercostal muscles are placed. Depress and elevate the ribs and note their motion.

From the abdominal side examine the diaphragm, its shape, its central tendon, and muscular sides.

Open one side of the chest and note that immediately the lung collapses.

Note the partition between the two sides of the thorax, each occupied by a lung.

Examine the relations of the heart to the lungs. Observe the manner by which the diaphragm may be moved by its own contraction, and by the action of the abdominal muscles.

While the lungs are still in place, trace out the trachea and larynx in the neck. Study the structure of each, making note of the cartilaginous rings and their action.

Introduce a tube into the trachea and inflate the lungs while still in the chest. Note all their connections, appearance, and properties.

Remove the trachea and lungs, and trace out carefully, as far as possible, the bronchi and their branches.

Study the pleura and its distribution. The pair of nerves going to the diaphragm may be seen as white threads running along on each side of the membranes which enclose the œsophagus and blood vessels. They, are the phrenic nerves.

While it is better to study the lungs in connection with the thorax, still

if such material is not at hand, the lungs of a calf, pig, or sheep, obtained from the butcher, is excellent material for illustration. It may be treated in the same manner as given for the rabbit.

The action of cilia may be studied in a frog's mouth. If the mouth of a live frog is held open, and a very small object, smaller than a pin-head —a piece of paper or cork—be moistened and placed on the roof of the mouth, it will be carried slowly down into the œsophagus. The motion here is the reverse of that in the human trachea.

If the roof of the frog's mouth be gently scraped with a knife-blade, and the scraping be mounted in water and examined under a good microscope, the cilia of some of the cells may be seen in motion. They do not live long thus removed, and must be examined quickly.

The motion and rate of respiration in one's own body should be observed very carefully, with a view to determine the position of the muscles in action, and the effects of different conditions, such as running, standing, etc.

Review Questions.

1. What is usually meant by the term respiration?
2. What do the living cells demand and produce?
3. Explain the act of respiration of a single- or few-celled animal.
4. What is true respiration?
5. What is the difference between internal and external respiration?
6. Of what does the respiratory apparatus consist?
7. Explain how the respiratory apparatus differs in different animals. Give examples.
8. What amount of surface is presented to the air by the lungs of human beings?
9. How can so much surface be presented in such small space?
10. Name the air passages to the lungs.
11. Describe an air sac or vesicle.
12. What is its relation to the blood vessels?
13. What is its function?

14. What are bronchioles?

15. Describe the trachea and larynx.

16. What is the structure of the trachea?

17. What is the use of the cartilaginous rings?

18. In what way are the air passages kept free from impurities?

19. How is blood supplied to the lungs?

20. What is the pleura?

21. Describe the thorax, giving its framework and the structure of its walls.

22. How is the diaphragm moved up, and how down?

23. What nerves supply the diaphragm, and what is their function?

24. By what is the diaphragm pierced?

25. Name and describe the muscles of the thorax used in breathing.

26. Describe the actions by which air is brought into the lungs.

27. Illustrate them by diagram.

28. What other muscles are used in forced inspiration?

29. How are the movements of respiration controlled?

30. Describe the action of expiration, giving the action of the muscles used.

31. Give a brief statement of the respiratory movements.

32. What is the respiratory center, and how is it stimulated?

33. What is the effect if the supply of air is cut off?

34. What other stimuli may throw the respiratory center into action?

35. Illustrate these relations by a diagram.

36. What is the rate of respiration in man?

37. How does it compare with that of the lower animals?

CHAPTER XIII.

CHANGES IN THE AIR IN RESPIRATION—VENTILATION.

Quantity of Air Breathed.—The amount of the air which is expelled from the lungs can easily be measured. It is found that an average of twenty cubic inches, about two thirds of a pint, is thrown out at each expiration, and taken in at each inspiration. This has been called the *tidal* air.

When a special effort is made, much more air can be expelled or taken in, but the lungs can not be completely exhausted. There always remain from one hundred to one hundred and thirty cubic inches, or about half a gallon. This is called the *residual* air.

Usually after an ordinary expiration at least two hundred cubic inches of air remains in the lungs. This, less the residual air, is called the *reserve* air.

The sum of the tidal, reserve, and residual air gives the volume of the lungs as two hundred and thirty cubic inches, or about one gallon. These numbers will be of value in estimating the amount of air required by the body. In active exercise part of the reserve air is added to the tidal air, the amount being according to the degree of activity.

Composition of the Air.—The air is a mixture, not a definite compound, of four gases, oxygen (O), nitrogen (N), carbonic dioxide (CO_2), and the vapor of water (H_2O). Out-of-doors the first three are very nearly constant in proportion, while the vapor of water varies greatly. When it is less in amount, we have a dry atmosphere; when greater, a moist atmosphere. Chemists can easily separate each of

these gases from the air, and by doing so have shown the composition of air to be as represented in the following table:

		By weight.	By volume.
In dry air,	Oxygen	23 parts.	20.96 parts.
	Nitrogen	77 "	79.02 "
	Carbon dioxide . . .	very small.	.03 to .034.

Diffusion of Gases in the Lungs.—If we should take any air-tight sac which opened externally by a tube, and should cause a certain amount of air to be expelled from it by pressing on its sides, it would be obvious that with slight pressure only the air immediately at the top of the sac next to the tube would be expelled. On slightly distending the sac, but a small amount would re-enter at the top to replace what had just been expelled. This is the case with the lungs, and it might seem impossible to get oxygen to the air vesicles and carbon dioxide away from them by such an apparatus. But these respiratory actions are supplemented by a property of gases known as that of *diffusion.*

Whenever two or more gases are placed in contact, each has the power to diffuse itself through the others. This they will do without regard to their relative weights or the relative quantities of each. To illustrate more fully, we may contrast this action with that of some liquids.

If mercury, water, and oil were so placed in a vessel that the mercury should be at the bottom, the water next above it, with the oil forming a layer on top, these three liquids would remain in the same positions an indefinite length of time. But if carbonic dioxide, oxygen, and nitrogen were placed so that the heaviest, carbon dioxide, should be at the bottom, oxygen next, and nitrogen at the top, no matter how carefully they were kept free from currents, still they would completely diffuse themselves through each other until every part of the jar would contain its proportional amount of each of these gases. This property of gases, by which

they are able to penetrate each other, is known as *diffusion of gases.*

This property comes from the tendency that gases have of occupying all the space at their disposal, and they find other gases so thin that they offer no resistance to this tendency.

As just stated, the relative quantity of the gases makes no difference in this action. If only a pint of carbon dioxide were placed in the corner of a large hall, it would, in time, become equally distributed throughout the whole hall. The apparent contradiction to this statement offered by the fact that sometimes, in wells, caves, or mines, accumulations of carbon dioxide or of other gases occur, is explained by the fact that in such cases there is a constant supply of the gases greater than the amount removed by diffusion.

If the gases acted like liquids in this matter, of course every quiet well, mine, and low place on the surface of the earth would fill up with carbon dioxide, over which layers of oxygen might form, and this arrangement be disturbed only by currents of air. As it is, the gases which constitute the air, with the exception of water-vapor, are about equally distributed over the whole globe.

Action of Diffusion of Gases in the Lungs.—With the property of diffusion in mind, it may be seen that if carbon dioxide or carbonic acid gas, in the residual air of the lungs, is of greater quantity, it will readily diffuse into the reserve air just above, and from this, in turn, to the tidal air, and while in this it will be expelled from the lungs by expiration. On the other hand, by an inspiration, the next installment of tidal air comes into the trachea and bronchi and bronchial tubes. The oxygen in it being greater in amount than in the reserve air, diffuses into it, and from it, into the residual air. By the same laws, the vapor of water passes from the depths of the lungs out. Thus, the respiratory acts drive out small quantities of air from the upper portions of the air

cavities and replace them with air from without, and the property of diffusion completes the transfer to and from the air vesicles.

Interchange of the Gases between the Blood and the Air Vesicles.—The law of diffusion just described acts also at the walls between the blood and the air; but that the blood may take up and hold firmly a sufficient quantity of oxygen, or discharge a sufficient quantity of carbon dioxide, certain chemical processes occur in addition to the act of diffusion. The indefiniteness of our knowledge of what all these changes are prevents a full statement of them.

But one thing is very clearly proved, and that is that the coloring matter of the red corpuscles, the hæmoglobin, under the conditions of the blood in the lungs—that is, lack of oxygen and abundance of carbon dioxide—combines with large quantities of oxygen obtained from the air and holds it until it is carried to the tissues, where the above conditions are reversed, and it gives up its oxygen. Thus the red blood corpuscles are the oxygen carriers. They may possibly act also as carriers of carbon dioxide on their return. At any rate, either they or other chemical substances in the blood, or both, help to remove carbon dioxide from the tissues and discharge it at the lungs. The water passes out of the blood by diffusion.

Amounts of Carbon Dioxide discharged and Oxygen taken up.—The amount of carbon dioxide expired in twenty-four hours will vary with the amount produced by the activity of the tissue cells, and this may be within a great range. If one is at rest and suddenly engages in violent activity, the amount of carbon dioxide is immensely increased. The amount of oxygen taken in will vary also with this activity. The comparison of the body to the engine may be recalled. The greater the heat or motion produced, the larger will be the amount of carbon dioxide produced, and the larger will be the amount of air containing oxygen required

In the human adult body an average of about 2.2 pounds of carbon dioxide is thrown off, and about 1.6 pounds of oxygen is taken up in twenty-four hours. In a child the amounts are twice as great as in the adult in proportion to their relative sizes.

Necessity of Ventilation.—The body has the power of storing up food to a considerable extent, so that it may pass days without taking any. It has less power of storing up water, and still less of storing up oxygen. This is, no doubt, because air is so abundant, being constantly about us. There being no need of a contrivance for storing what is ever at hand, no such contrivance has come to the body.

If we continually lived out-of-doors, as was probably the case with our primitive ancestors, no inconvenience might be felt. But living and working in the confined space of houses, we are constantly in danger of placing the body in air greatly changed in the relative amounts of its gases from that to which the body is adapted.

Any change which will affect the relative amount of oxygen must be considered as injurious, even to its being fatal, if the change is a great one. Our ordinary respiratory processes are just sufficient to supply us with the required amount of oxygen when the proportions are as given in the table in the first part of this chapter. Now, if any part of this normal amount of oxygen is either removed or diluted by the addition of any other gas, even a harmless one in itself, the air so changed is unfit to breathe in proportion to the amount of the change.

Expired Air.—It has been stated in a former section that at each expiration about twenty cubic inches—about two thirds of a pint—of air is thrown out. This air contains a large amount of carbon dioxide, considerable water vapor, and certain organic substances, the exact nature of which is not known. This air is lacking in oxygen. The small amount of organic substances seems to be especially injuri-

ous if breathed again. Carbon dioxide itself is not a poison, but acts by its presence to dilute the oxygen. The organic substances are so small in amount that they can not be weighed. Their presence is known by such effects as drowsiness and headache, and by their giving to the air an unpleasant odor. Since their amounts increase as the carbon dioxide increases, and this last is measurable, its amount is used to indicate the amount of the poisonous gases present.

Let us follow a calculation that has been made to give a basis for the ventilation of rooms. At each expiration twenty cubic inches of air is thrown out. In one hour the lungs exhale $20 \times 18 \times 60 = 21600$ cubic inches, which is about twelve cubic feet. One cubic foot of ordinary air contains about .0005 of a cubic foot of carbon dioxide. When a cubic foot of air contains more than .0007 of a cubic foot of carbon dioxide it is unfit to breathe, not from the carbon dioxide, but from the amount of the other substances which have been found to accompany it.

In one hour the lungs throw off about .6 of a cubic foot of carbon dioxide. This .6 will bring the carbon dioxide of 3000 cubic feet of air to the danger line of .0007 cubic feet of carbon dioxide to one foot of air. In other words, an adult will make 3000 cubic feet of air unfit to breathe every hour.

From this it will be seen that six persons will render the air of an unventilated room, $30 \times 40 \times 15$ feet, unfit to breathe in one hour. Twelve would accomplish this in half an hour. Let the reader apply this calculation to the rooms in which he works and sleeps, and from it he can determine how long the air in such rooms will suffice for those who occupy them.

We have been discussing only those substances which are thrown off by the lungs, but, as we shall see in more detail in another section, the skin adds greatly both to the carbon dioxide and the organic substances. Consequently, the above calculations give smaller numbers than should really be our guides in the matter of ventilation.

It is plain from what precedes that a few persons could exist a considerable length of time in a very large closed space without danger, or that a number of persons could exist in a small space provided the air were changed often enough. In either case the conditions should be in accordance with the figures given above. If any deviation is to be made from them, it should be in allowing more air instead of less.

It should not be forgotten that to maintain health it is absolutely necessary to have the requisite amount of oxygen and the air free from poisonous gases. No other thing can make up for changes in these respects. It is generally recognized that the sick-room should be well ventilated, but an active, healthy person uses more oxygen and produces more carbon dioxide, and hence should have at least a room as well ventilated.

Notes on Ventilation.—The ventilation of a room is the removal and replacement of the air in it. This is accomplished in various ways, by windows, doors, special ventilating shafts, etc. Ventilation can easily be accomplished by one who will remember that hot air is lighter than cold air, and will, in consequence, rise, causing currents. He can arrange, then, the openings of the room in such a way that these currents may be made to bring air into the room and carry it out.

When a room is heated by some radiating surface, such as a stove, steam or water pipes, or by the hot coals in a grate, it is evident that the air entering the room will be cold, while that which escapes will be warm. This will necessitate a considerable loss of heat, together with a greater or less amount of cold draughts. The best arrangement will be that which will introduce the cold air as near the heating surface as possible, and cause the warm to circulate through the room to the greatest extent. Every room has its own peculiarities, and needs especial attention to secure its ventilation.

Heating by means of hot-air furnaces offers the most perfect system of heating with ventilation, as by its means the room can only be warmed by the introduction of fresh air and driving out the old air. As in it the air introduced is the warmer, and that removed is the colder, a different arrangement of the ventilating openings must be made from that in use with heating from radiating surfaces. If an aperture near the ceiling of the room heated by a furnace is left open, the pure warm air rises from the register and escapes, leaving the less pure and colder air in the room, thus wasting both heat and good air.

There is a popular notion that warm air is bad, while cold air is always good. This is a great mistake, for the temperature of the air has nothing at all to do with its purity. The most impure air may be very cold, while the purest air may be very warm.

Foreign Substances in the Air.—There are many poisonous gases which, on being introduced into the air in the lungs, may be absorbed into the blood and have very deleterious effects on the living cells of the various tissues. Many of these are only met with in the manufacture or handling of chemicals. Other gases rise from cesspools and sewers, which have been shown to be very dangerous. These should not be allowed to come into the neighborhood of living-rooms.

In all the air in our dwellings there is a large amount of dust. Some of this is harmless, and if not in too great quantities can be removed by the cilia of the air passages, but this dust may contain the germs of different diseases, which, finding lodgment in the air passages, may give rise to these diseases. In some cases the source of the germs is from patients who are suffering from scarlet fever, diphtheria, and certain other fevers. In these cases, that the disease may not spread, those in danger of taking the disease should not be allowed to come near the sick nor inhale air from the room,

and the furniture, clothing, and articles touched by the sick person should be thoroughly cleansed and disinfected before they are again used.

All living and sleeping apartments, even when occupied by those in good health, should often be cleansed and thoroughly aired, as the organic substances thrown off from the body, which are so injurious, are likely to adhere to the walls and furniture of the room, and, in time, become worse by accumulation. Wash out the room with air and water. Pure air, good food, clean water, and abundant exercise are the basis of good health.

Directions for Practical Work.

By the methods given in any text-book in chemistry, make oxygen, nitrogen, and carbonic acid, and study their properties. These are easily made and can be shown in any school-room. The directions would occupy more space than can be given here, and the books are easily accessible.

Make some lime-water, for a test for carbon dioxide, by shaking up some lime with water in a bottle, and after allowing it to stand, pour off the clear solution.

Shake some of the lime-water with carbonic dioxide, as made above. It will make it milky in appearance by the formation of carbonate of lime. As no other gas will do this with lime-water, it is used as a test for carbon dioxide.

Catch some of the gas from the top of a candle or lamp flame, and test it with the lime-water, and it will be found to contain carbon dioxide.

Breathe into a glass at the bottom of which is some lime-water. It will show the presence of carbon dioxide in the respired air.

Breathe on a cold glass, and the deposition of water will show its pres ence in the respired air.

Construct a model of a room from a box, not less than a foot each way. Cut holes in it at various points, for windows, which may be opened or closed by strips of paper pasted on them or torn off, as needed in the experiment. Cut a large hole in the top, over which may be laid a piece of glass. This arrangement will allow a view of the interior of the room. Small bits of candles may be used as stoves in this room. With the model study out the best arrangement to secure ventilation. If the ventilation is not good the candles will go out. The direction of the currents may be shown by

smoke from burning paper. A good way to make paper that will smoke without blazing is by soaking brown paper or blotting paper in a solution of saltpeter and letting it dry.

Review Questions.

1. What is meant by tidal air? Residual air? Reserve air?

2. What is the amount of each and the whole volume of air in the lungs?

3. Give the composition of air.

4. What is the property of the diffusion of gases?

5. Illustrate how it may act.

6. How do gases compare with liquids in this respect?

7. Why can gases diffuse into each other?

8. What effect do the relative quantities of gases have on this property?

9. How does this principle act in the lungs?

10. Draw a diagram showing how the oxygen of the air reaches the air vesicle, and the carbon dioxide passes out.

11. How do these gases pass to the blood, or out, as the case may be?

12. How is the oxygen taken to the tissues?

13. What is the function of the hæmoglobin? Where is it?

14. How much oxygen is taken up in a day?

15. How much carbon dioxide is thrown off by the lungs?

16. What conditions bring about the necessity of ventilation?

17. What are the constituents of expired air?

18. What is the most deleterious of these substances?

19. How is the dangerous amount detected?

20. Give the calculation showing that a person will render 3000 cubic feet of air unfit to breathe in one hour.

21. What are other sources from which deleterious substances from the body get into the air?

22. How is a room to be ventilated?

23. How in the case of a stove? How with a furnace?

24. Draw a diagram showing what are the currents of air in a room with different heating apparatus, and with windows opened or closed at different positions.

25. What foreign substances may be in the air?

26. How should sleeping apartments be treated?

27. What care should be taken in rooms occupied by the sick?

CHAPTER XIV.

THE VOCAL APPARATUS.

Movements of the Vocal Apparatus.—The larynx, placed at the top of the trachea, constitutes a very delicate piece of mechanism, which is able to work with surprising rapidity and with precision for hours at a time. A speaker may use one hundred and fifty words a minute, and each word requires several movements of the muscles of the larynx and respiratory apparatus, which, if not accurately made, would result in wrong sounds. A skillful singer can, in the course of a song, render a great number of notes without striking a false one. This requires very great accuracy in the rapidly succeeding movements, for the change in the motion of a muscle so slight as not to be perceived by the eye would make a changed note easily detected by the ear.

The voice is produced by currents of air passing over the vocal cords in the larynx, while stretched tightly, and with their edges parallel.

The Larynx.—The larynx is a special modification of the upper portion of the trachea. The cartilages, which in the trachea are in rings, are in the larynx so changed as to form parts that will allow many motions. The main cartilages of the larynx are as follows:

The *cricoid* cartilage, which stands at the base of the system, is placed on the top of the trachea. It is a heavy ring, much wider behind.

The *thyroid* cartilage is the largest in the larynx, and consists of two flat plates, which unite in front but are wide apart behind. This cartilage can be felt

just beneath the skin in the front part of the neck, and is known as "Adam's apple." Its upper front margin has in it a deep notch, which can be easily detected. This cartilage rests by two points at the posterior angles of its lower margin on the cricoid cartilage, at which points true joints are formed, allowing it to work up and down with the cricoid as a firm base.

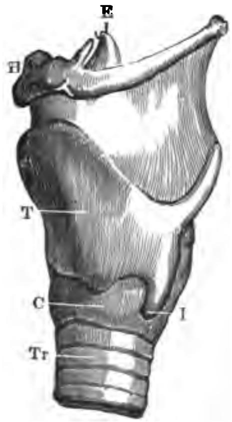


Fig. 62.

LARYNX—SIDE VIEW.

T, thyroid cartilage; *C*, cricoid cartilage; *Tr*, trachea; *H*, hyoid bone; *E*, epiglottis; *I*, joint of thyroid cartilage.

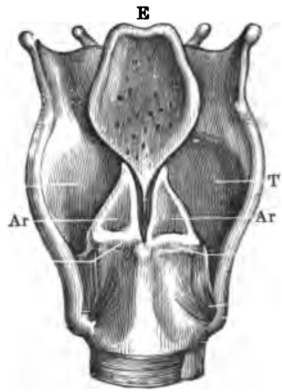


Fig. 63.

LARYNX—BACK VIEW.

Ar, Arytenoid cartilages; *T*, thyroid cartilages; *E*, epiglottis.

The *arytenoid* cartilages, two in number, are small, three-sided pyramids, which rest upon the upper margin of the posterior portion of the cricoid cartilage, with which they articulate by true joints. The summits of these cartilages approach one another, and are extended by two other small cartilages on each of them.

The *epiglottis* is a cartilage attached to the upper front

part of the larynx. It projects upward just behind the base of the tongue, except in the act of swallowing, when the whole larynx is thrown upward, and the epiglottis is brought up and thrown over the upper opening of the larynx, completely covering it. It is brought into this position also in the beginning of a cough. The closure in swallowing is evidently to keep foreign bodies out of the larynx and air passages. This action takes place also in attempting to breathe certain poisonous gases. The closure in the beginning of a cough is to hold the air a moment in order to allow it to rush out suddenly, and thus remove any foreign body.

The cartilages of the larynx are held together by numerous ligaments, and are moved by many muscles.

Just above the thyroid cartilage is the hyoid bone, to which it is attached by ligaments and muscles.

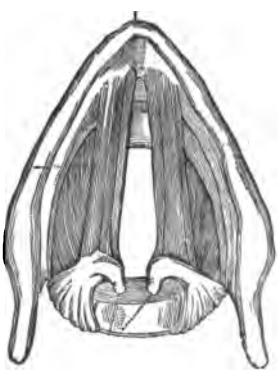


Fig. 64.

SECTION OF LARYNX, SHOWING THE LIGAMENTS OF THE VOCAL CORDS WITH THE MUCOUS MEMBRANE REMOVED.

The Vocal Cords.—The interior of the larynx is lined by a mucous membrane. In about the middle of the larynx the passage is much narrowed by two pairs of folds in its walls, the lower pair being the *true vocal cords;* the upper, the *false cords.*

In the folds constituting the true vocal cords are ligaments and muscles, which run from the arytenoid cartilages forward to the angle formed by the plates of the thyroid cartilage. The edges of these folds are very thin, and are capable of being stretched tightly and brought very close together, and parallel, by the action of muscles on the aryte-

noid and thyroid cartilages. Some draw the front part of the thyroid down; others throw the arytenoids very close together and hold them firmly in position.

The Production of the Voice.—A vocal sound is produced by bringing the stretched edges of the vocal cords close together and parallel to each other, leaving a very narrow slit between them, and while in this condition forcing a current of air past them. The sound is produced by the vibration of these stretched elastic membranes, in just the same manner as it is produced in all reed instruments. The arrangement is shown in many forms of toy trumpets, in which either a thin strip of metal or of india rubber partially closes an opening through which the air is made to pass.

Action of the Air Cavities around the Vocal Cords.—As in most musical instruments, there are arranged about the vibrating parts air cavities, whose air, by being thrown into vibration, greatly strengthens the sound. These are called resonating cavities. In the production of the voice all the air passages above the larynx may act as resonators.

Properties of Sound.—In the study of physics we learn that there are three properties in which sounds may differ, viz.: in *pitch*, in *intensity* or loudness, and in *quality* or character.

The *pitch* of a sound depends on the rate of its vibrations—that is, the number per second—and the rate depends on the thickness, length, and tensity of the vibrating reed or string (the vocal cords in the larynx). For example, C of the key of C has 256 vibrations per second, while the octave above has 512. It has been recorded that among singers a bass voice has reached the very low note of a contra F, at 42 vibrations per second, while soprano voices have reached A‴, of 1708 vibrations.

The *intensity* of a sound depends on the intensity of the vibrations in the larynx, and this on the strength of the blast of air and its manner of application to the cords.

The *quality* of a sound is that property by which two notes made by different instruments of the same pitch and intensity can be distinguished from each other. In the human voice it is that by which one voice is distinguished from another.

A fuller explanation of this property than can be given here is needed to make the matter perfectly clear. Still, it may be stated to depend in most musical instruments upon their resonating air cavities, and on the size and shape of the cavities. Every vibrating reed or string gives off many tones at the same time; a resonating body of air can only take up certain of these, according to its size and shape. If the resonator varies ever so little in size or shape, it emphasizes different tones. Consequently, if all people had exactly similar vocal cords, the quality of the voice of each would differ as the size and shape of the air passages of each differ from those of all the rest, which is the case, at least in a slight degree.

The quality of the voice of a single individual is instantly changed by any change in the shape of his air passages. For example, raising or lowering his chin, putting substances into his mouth, pressing on his trachea, throwing his shoulders back or dropping them forward, will change the quality of his voice.

One may improve the tones he uses by taking care to hold his body in the proper position for their production. What that position is he can easily find by experimenting on himself in this matter. The difference between all the sounds of the alphabet is made by changes in the resonating cavities.

The Sounds for Different Letters.—The sounds represented by the different letters may be thrown into the following classes: those which depend fundamentally on the vibrations of the vocal cords, and those in which the vocal cords take no part, but which depend on the rushing of the air along the upper air passages. The first includes the

vowels and the sub-vowels, and the second the remainder of the sounds of the alphabet.

In producing a vowel sound, the air escapes unhindered through the mouth. In making the sub-vowels, the mouth passages are more or less obstructed, the escape of the air being more or less through the nose. It would be profitable for the reader to study before the mirror, and with thumb and finger on the larynx, the movement of the parts engaged in making each sound represented by the different letters.

Training the Voice.—The wonderful vocal feats performed by professional singers and others serve to show to what extent the voice is susceptible of training. The laryngeal muscles and those of respiration used in speaking are under the complete control of the will. One can improve his manner of speech as readily as he can his manner of walking or managing his hands.

Habits of speaking distinctly, and in clear tones, and with a pleasant and intelligent expression, are matters that can be acquired by attention as easily as their opposites can be acquired by carelessness.

To the fact of the great development of articulate speech in man is no doubt due to a considerable extent his great intellectual advancement. Since the meaning of oral sentences depends in part on the manner in which they are spoken as well as on the choice of words, there is good reason for an attempt to get a more perfect and intelligent control of the apparatus.

Hoarseness.—This affection is due to an inflamed condition of the cords or an accumulation of mucus on them. The inflammation may be due to a slight congestion occasioned by long speaking while not properly using the larynx, or it may be due to a cold which affects these parts, or to some of the diseases which may affect the throat. If due to the first-mentioned causes, it is obvious that the care needed is rest for the organs. If due to the last, only the

advice of those who have the proper knowledge in such matters should be followed.

The Voice of the Lower Animals.—In the mammals the larynx is present, and is used to produce the various sorts of calls or expressions of emotion of which they are capable. In the birds the true larynx is placed at the division of the trachea into the bronchi. In some of these animals it has a wonderful power.

In animals lower than birds there is no well-developed vocal apparatus, and in most it is absent. Among insects various means are made use of to produce sounds, such as rubbing together various parts of the body, or by rapid vibrations of the wings, by a vibrating membrane, or by forcing air out of their breathing pores, called spiracles.

The thyroid body and the **thymus gland or body** are not parts of the vocal apparatus, but as they are attached to them, they may be described here.

The thyroid body is a two-lobed body attached to the front and sides of the larynx and trachea. Its lateral portions extend from the side of the thyroid cartilage to the fifth or sixth cartilaginous ring of the trachea. It is full of vessels. Its function is not agreed upon by physiologists.

The thymus gland is a small body, only appearing in childhood, and gradually disappearing as the child becomes older. In children of two years, it extends along the trachea down into the thorax, along the back part of the sternum, to about the position of the costal cartilage of the fourth rib. This and the thyroid body are called ductless glands, but their structure is not that of typical glands. The function of the thymus gland is not definitely known.

Directions for Practical Work.

For the study of the larynx that of a large animal is perhaps best. Special directions must be given to the butcher in ordering it, or it will be delivered much mutilated.

In it, make out all the cartilages described in the text. Tear away the connective tissue and very clearly will be shown the muscles which move them. Make out the vocal cords.

Examine the manner of the action of the epiglottis.

If the tongue is also obtained with the larynx, the hyoid bone and its attachment to the larynx and tongue may be studied.

Study the properties of sound by means of a violin or guitar. Pitch, intensity, and quality, and on what they depend, may be illustrated by these, by tightening, loosening, shortening, etc., the strings.

Study the human larynx in action: the shapes of the mouth in making the different letters, and the effects on the quality of the voice by the assumption of different positions of the body.

Review Questions.

1. What is said of the accuracy of the vocal apparatus?
2. Describe the larynx.
3. Locate each of the cartilages.
4. How are these cartilages held together?
5. How are they moved?
6. Give the position of the vocal cords.
7. Describe them in action.
8. How is the voice produced?
9. What is the action of the air cavities in the production of sound?
10. What are the properties of sound?
11. Upon what does each depend?
12. Upon what do the differences in the voices of different individuals depend?
13. How are differences in the sounds of the letters made?
14. What is said of the training of the voice?
15. How can one change the quality of his voice?
16. What is the cause of hoarseness?
17. How is voice produced in the lower animals?
18. Give the position of the thyroid body.
19. What is its function?
20. Where is the thymus gland, and what is its function?

CHAPTER XV.

THE SKIN AND THE KIDNEYS.

General View of the Skin.—The outer covering of the body, the *skin*, is very complex in its structure, and possesses several different functions. Being the part immediately in contact with the outside world, it gives us much of our knowledge of the world, and at the same time protects the other working parts from injuries that might come to them. It also serves to regulate the temperature of the body. How these important offices are accomplished will be better understood when its structure is known.

It covers the whole external surface of the body, its outer layer being the outer wall of the double tube in which the body was considered to be formed. (See Chapter II.) The skin is thickened on the palms of the hands and the soles of the feet, thin and very flexible over the joints, thin and transparent over the eye balls.

Its average thickness is about one tenth of an inch. It is, by means of connective tissue containing elastic fibers, tied to the parts beneath in such a way as to allow great freedom of motion, and yet firmly enough to keep it in the same place. The elastic fibers bring it back when it is temporarily pushed aside.

Structure of the Skin.—The skin consists of two distinct portions, the outer layer, called the *epidermis*, resting on the second layer, the *dermis*.

The epidermis, sometimes also called *cuticle*, is composed of a mass of cells (Figs. 1 and 65) whose walls are cemented together. It contains no blood vessels, and no nerves except

a few very fine fibrils among the lowermost layers. Among the lower layers are pigment cells, the number of which determines the color of the skin.

Loss and Growth of the Epidermis.—The outer layers of the cells of the epidermis are constantly falling away. The friction of external objects constantly removes them. The epidermis is removed by the growth and reproduction, by division, of the lower layer of cells. These receive their nutrition from the plasma of the blood, which diffuses to them from the capillaries in the dermis beneath. By this constant waste and renewal the body has always a comparatively new cover.

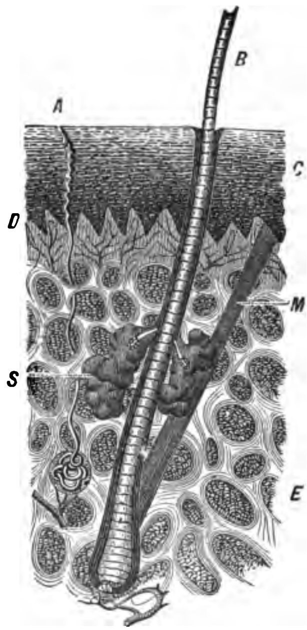


Fig. 65.

DIAGRAMMATIC SECTION OF THE SKIN.

C, epidermis; *D* and all below is dermis. At *D* papillæ are seen; *B*, a hair; *A*, duct of sweat gland; *M*, muscle fiber; *E*, fat; *S*, sebaceous gland.

Functions of the Epidermis.—The epidermis protects the parts immediately beneath from mechanical injury. By being impervious to liquids, it prevents the absorption of poisons from without and evaporation from within. The loss of water occurs only through the sweat glands, which loss can be regulated.

The Dermis.—The lower layer of the skin is the thicker. It is formed of a network of connective-tissue fibers, of both the elastic and the inelastic varieties. This layer of connective tissue makes a tough, flexible sheet, which envelops the body. Lodged among the fibers and supported by them are:

1st, a fine network of blood vessels;
2d, a fine network of nerves;
3d, a fine network of lymphatic vessels;
4th, immense numbers of sweat glands;
5th, great numbers of sebaceous or oil glands; and
6th, numerous organs of touch—*touch corpuscles.*

The networks of nerves and of blood vessels are of so fine a mesh as to make it impossible to push a needle through them without wounding some of each.

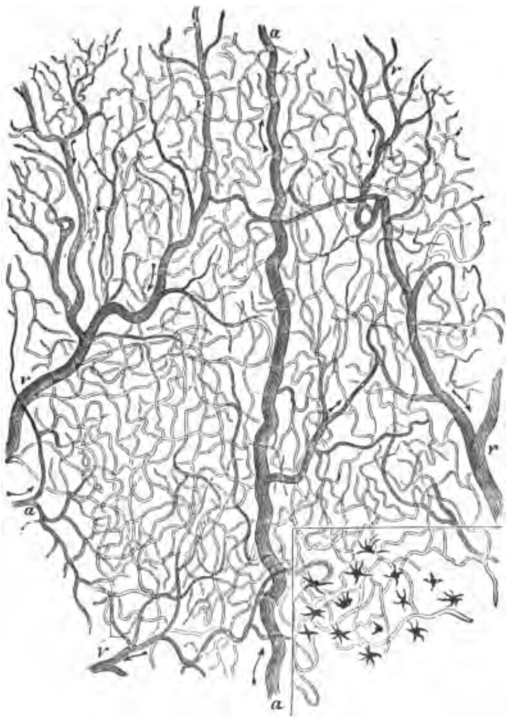


Fig. 66.

CAPILLARY BLOOD VESSELS FROM SKIN OF WEB OF FROG'S FOOT.
a, arteries; *v*, veins.

The arrangement of the blood vessels could be seen with the microscope in the web of a frog's foot, when examined by the method given in the chapter on Circulation, shown in Fig. 66. In every place the dermis is thrown up into numerous little projections called *papillæ.* As the epidermis is molded over these and fills up the valleys

between them, they do not show well on the surface of the skin. But on the palm of the hand and the corresponding surface of the fingers, where the papillæ are especially numerous, they are crowded into rows, a hint of which is found in the parallel ridges and furrows seen in the epidermis of those surfaces.

Fig. 67 shows the papillæ of the dermis with the epidermis removed. Each papilla contains a loop of a capillary vessel and a nerve fiber. Many have at their summit a peculiar arrangement of cells, which is thought to be an organ of touch, and, consequently, called a *touch corpuscle.*

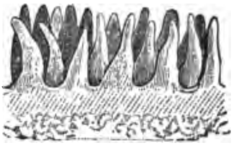


Fig. 67.

PAPILLÆ FROM PALM OF HAND, WITH EPIDERMIS REMOVED.

In the lower layers of the dermis, the connective-tissue fibers form a more open network, which gradually passes into the connective tissue fibers which attach the skin to the parts beneath, and called for that reason the *subcutaneous tissue.* In the loose, lower network are placed little masses of fat. On the amount of this fat depends the smooth or wrinkled condition of the skin.

Sweat Glands.—The sweat glands, or *perspiratory* glands, are little tubular glands whose ducts open through the epidermis on the outer surface of the skin (*A* in Fig. 65). The secretory part of the gland is lodged in the lower layers of the dermis, where the tube is coiled into a small knot. This is surrounded by a network of capillaries, and is also supplied by nerve fibers.

The lining of the coiled part is composed of *gland cells,* which, when stimulated by the nerves, under the control of the nervous system, secrete the perspiration. The cells obtain their supply of material from the blood so copiously furnished them. The supply of the blood, be it remembered, is also under the control of the nervous system.

Sebaceous Glands.—The sebaceous glands are small glands which open into the little pits out of which the hairs grow (*S* in Fig. 65). They secrete a kind of oil, which renders the epidermal layer less pervious to water, and prevents it from becoming dry and cracking open. It also softens the hair and keeps it from becoming brittle.

The Lymphatics are very numerous, and are arranged in a network, some originating in the skin. They, as well as the blood vessels, will readily absorb any liquid introduced under the skin, as is illustrated by the *hypodermic* injection of medicines, which is practiced by some physicians.

Function of the Dermis.—Both the sweat glands and the sebaceous glands are to be considered as continuations of the epidermis into these tubes or pits, the cells of which have become secreting instead of protective cells—another example of the "division of labor." Besides the protection afforded by the layer of epidermis, as given in a former paragraph, the dermis affords still greater protection as a tough, partially elastic web clothing the body. It thus helps to deaden blows. It prevents the parts beneath from being bruised, lacerated, or rubbed. What a suit of buckskin clothing or one of strong cloth would do for the skin, the skin does better for the rest of the body beneath.

The Skin as an Excretory Organ.—The three great organs for disposing of the wastes of the body are the *lungs*, the *skin*, and the *kidneys*. Each one of these throws off a certain amount of water. Each one also throws off some carbon dioxide. The greatest amount of carbon dioxide is thrown off by the lungs, while the greatest amount of water is disposed of by the skin.

The sweat glands are very numerous, the secreting cells making a sum of secreting surface which has been estimated to be about eleven thousand square feet. From this great surface a certain amount of perspiration is constantly passing away. Usually the amount from each gland is so small

that it evaporates as soon as it reaches the surface, and is not visible, and from this it is called "*insensible perspiration.*" Its existence can be readily detected if the hand be pressed against a piece of cold glass, in which case the surface of the glass becomes instantly coated over with moisture.

When the secretion of the sweat goes on more rapidly than does the evaporation at the surface, the sweat appears in drops. This is called "*sensible perspiration.*" Of course, the amount of moisture in the atmosphere will affect the amount of perspiration which appears as sensible. This distinction of sensible from insensible is an unimportant one. The amount of this secretion varies greatly, but will average about one and one half pints in a day.

The Skin as a Regulator of the Temperature of the Body.—The conditions of the body demand a constant temperature of its organs. This is about 98° F. A variation of but a slight amount from this degree is attended with fatal results. It is a very difficult problem to keep a room at a constant temperature. One has in such a case two classes of things to consider—the regulation of the fire for heating the room, and the regulation of the means of cooling the room. By giving one's whole attention to the matter, he could hardly succeed in keeping a room at the even temperature of 98°.

The body does this for itself through the changes of the seasons, or of the climates through which it may be required to pass, or in the more difficult matter of passing from a warm room into a cold atmosphere, or *vice versa.*

The method of furnishing the heat we will consider in another section. It is by means of the skin that the cooling is accomplished.

This is done in two ways. The body is generally in an atmosphere colder than itself, to which it radiates heat from the skin. By means of the nervous system it can allow greater or less blood to pass to the skin, which, losing its heat at this

point, will again, circulating through the rest of the body, cool the whole.

The other method by which it loses heat is by evaporation. In the study of Physics we are taught that the evaporation of even a small amount of water uses up a large amount of heat. In the evaporation of the sweat poured out on the surface of the skin the body is cooled, the amount of cooling depending on the amount of the water thrown out.

Nervous Control of the Heat-regulating Apparatus.—It is plain to be seen that if these two methods of cooling the body are under control, they can be an important means of regulating the temperature of the body

As both the blood vessels supplying the skin and the sweat glands are under nervous control, if impulses coming from any part of the body to the nerve centers which control the blood vessels of the skin and sweat glands, show that the temperature in the body is rising above or falling below the proper degree, these centers immediately send out impulses which increase the blood supply to the skin and the amount of sweat secretion, with the effect of cooling of the body, and impulses which decrease those actions have the opposite effect.

This is another of the wonderfully sensitive self-regulating mechanisms of the body, which, like those of the circulatory organs and the organs of respiration, is so delicately balanced as to answer to the slightest change in conditions. Man has invented several forms of mechanisms to regulate the temperature of a room or a heated body which have been greatly admired for their ingenuity, but none work so perfectly as this of the human body.

The Skin as an Organ of Special Sense.—The skin, as has been mentioned, holds the touch corpuscles, and thus becomes the organ of touch. It also determines the temperature of things. These two extremely important functions we shall pass here with the mere mention, as they are to be discussed under the chapter on the *Special Senses.*

It may now be repeated that the skin is one of the most complex in structure and one of the most important in function of the organs of the body, standing as it does at the outer boundary of the little world in which the body lives.

The Hair.—Both the hair and nails are modifications of the epidermis. The hairs are little cylinders of epidermis very much prolonged. Each hair is formed on the top of a papilla of the dermis which stands in the bottom of a pit in the skin (see *B* in Fig. 65). The epidermal cells on the top of this papilla grow just as they do elsewhere, but they adhere together in such a way as to form a column, which protrudes from the pit, or "hair follicle," as it is called.

This column of epidermal cells making a hair may become several feet long, but the only point at which it is *living* and *growing* is just at the top of the papilla, which is at the bottom of the follicle. From this it is evident that the common notion that cutting off the ends of the hairs, either by shaving or otherwise, will cause them to grow better and stronger is not correct.

Where a hair has begun to split at the outer end, cutting off this portion may stop the process of splitting and thus prevent the wearing away of the hair, and by this means allow it to grow longer, but it has no effect whatever on its manner of growth. Hairs are distributed all over the surface of the skin except on the palms of the hands and the soles of the feet.

The Nails.—The nails are, like the hair, growths of the epidermis. The growth of the nail takes place at the extremity which is buried in the skin, where a mass of papillæ forms layer after layer of cells, which, adhering together firmly, form a sheet of very firm epidermis. This is pushed forward over the end of the finger as the nail. It might well be compared to a very wide, flat hair.

The nails stiffen the ends of the fingers, and render effi-

cient aid in handling small objects, in such acts as pulling pins out of clothing or small splinters out of the skin.

The Skins of other Vertebrates.—The skin in the lower animals is formed on the same plan as that in man. The epidermal portion, however, varies exceedingly in form. In birds it takes the forms of beaks, claws, and feathers, with their wonderfully complex shapes and colors. In other animals are seen the variously shaped and colored hairs, hoofs, horns, scales, plates, knobs, ridges, and callosities of many kinds.

All these are modifications of the outer surface of their bodies, to adapt them to act on the outer world to the best advantage in the peculiar position in which each lives.

It is a very profitable exercise to study out some of these adaptations of the skins of the most common organisms around us to their conditions of life. Such study would serve to emphasize the immense importance of the skin as the organ which connects organisms with the forces of the outer world. Advanced investigation in these lines show that even the sense-organ cells of the eye, of the ear, of taste, and of smell are but complex modifications of the skin. Consequently, it may be said that, beside the other important functions, the skin, with its modifications, is our only source of all such knowledge as we obtain through the senses.

Care of the Skin.—Almost the whole of the hygiene of the skin would be expressed in the words, *keep it clean.* The sources from which it becomes unclean are its own secretions, the cast-off epidermal cells, and foreign bodies coming in contact with it. These should be removed, as their accumulation interferes with the performance of the functions of the skin, and they may become places for the lodgment of poisonous germs of disease, which, while they may be kept out of the body by the protective action of the skin if it remain unbroken, may yet be introduced by an unfortunate wound, or even a slight scratch.

Many of the cases of fatal effects following a slight wound have been due no doubt to such germs being introduced into the body. Of course, the poisonous matter may sometimes be on the wounding instrument.

Aside from any considerations of health, every well-bred person will keep his body clean.

Bathing.—It is the duty of such a text-book as this to insist that the body should be kept clean rather than give directions for accomplishing that purpose. The time and frequency of washing or bathing should certainly be governed by the necessities of keeping clean, and should evidently vary with the kinds of occupations in which one is engaged, or the conditions in which he is working.

No fixed rules that would be of general application can be given. The subject of bathing, like many other subjects in regard to the care of the health, has been a fruitful subject of much advice and varied forms of directions. But if the reader will keep in view the object of the bath and its importance, and be guided by the true meaning of comfort and discomfort in the bath, he may confidently arrange his own programme for his baths, and feel that he has the temperature of the water about right.

The Kidneys.—The kidneys have been mentioned as one of the three great excretory organs. Of the three principal wastes of the body, carbon dioxide, water, and urea, the last is the only one which contains nitrogen. Urea is one of the substances formed by the kidneys, and discharged by them. It belongs to the group of ammonia compounds, and contains oxygen, carbon, hydrogen, and nitrogen.

The substances from which the urea is derived are formed in the tissue cells during their activity, and are discharged by them into the blood. The blood carries them along until they reach the kidneys, where they are taken up by the kidney cells, and, as urea dissolved in water, are thrown out of the kidneys to be carried away from the body.

The Structure of the Kidneys.—The kidneys are a pair of bean-shaped glands, about four inches in length, placed in the loin, one on each side of the spinal column near the last dorsal vertebra, and the first two lumbar vertebræ. Each one is supplied with a large artery, the *renal artery*, which in the substance of the kidneys divides and subdivides in a manner peculiar to the kidneys.

The branches give rise to little bunches of capillaries, which in turn are the source of a very fine network of capillaries, which spread through the secreting portion of the gland. These capillaries are gathered into veins which find their outlet in the renal vein.

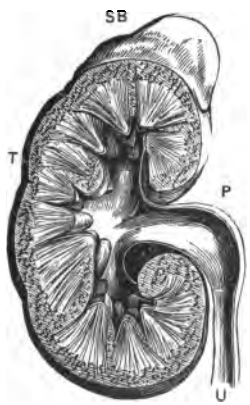


Fig. 68.

SECTION OF A KIDNEY.

P, pelvis; *T*, secreting part; *SB*, supra-renal body; *U*, ureter.

The secreting part of the kidney consists of an immense number of long microscopic tubes which wind in and out among each other in a very complicated manner. They originate in little capsules by which the bunches of the capillaries mentioned above are inclosed in such a manner as to act to each as a funnel to catch the liquid which may exude from their walls. The next part of the tubule is lined with true secreting cells. These are enveloped by the fine network of capillaries, also mentioned above.

These tubules empty their contents into larger tubes, and these open into still larger ones, until one duct comes to answer as the common outlet of a large number of tubules. This common duct opens into a space in the inner side of the kidney, called the pelvis. A number of such ducts open into this space from the different parts of the kidney. The pelvis narrows into a tube called the ureter, which conveys the

secretion away from the kidney to the bladder, which serves as a reservoir for it until it is removed from the body.

Nervous Control of the Action of the Kidneys.—Like the other excreting as well as secreting organs, the kidneys are under the control of the nervous system, both in regard to their blood supply and the activity of their secreting cells. These are constantly adjusted to the amount and kind of nitrogenous wastes to be got rid of. These wastes, if retained in the body for any great length of time, produce fatal results.

Effects of Alcohol on the Kidneys.—The kidneys, as we have just learned, form an extremely important organ, being one of the three great excretory organs. The secretions of the kidneys if retained in the body would soon produce death. If these secretions are imperfectly separated from the blood, serious results will occur, corresponding in degree to the imperfection of the action of the kidneys.

When alcohol is taken into the stomach and absorbed into the blood, the kidneys immediately begin to discharge it from the body. The presence of much alcohol irritates the cells of the kidneys, interferes with the regulation of their blood supply, and thus disturbs their normal action. Long-continued use of alcoholic drinks will make permanent changes in the structure of the kidneys, such as fatty degeneration, or a considerable development of connective tissue replacing the proper cells of the tubules. With these changes go disordered functions, which result in very serious diseases which often end fatally.

As an example of some of these, a large number of cases of Bright's disease are traceable to the use of alcoholic drinks. As with the liver, so with the kidneys, the troubles following the disturbance of their normal functions are numerous. It must be remembered that both these important organs, as well as others in the body, are simultaneously affected, which only makes matters worse

for each one. This complication makes it difficult, often impossible, to say how far each of the many bodily disorders which result from the use of alcoholic drinks may be specifically traced to the disturbance of the functions of the kidneys by alcohol. For fuller discussion of the effect of alcohol on the body the student is referred to Chapter XXII., pp. 288–294.

Directions for Practical Work.

If the surface of the palm of the hand be examined with a hand lens, the ridges which correspond with the rows of papillæ beneath can be distinctly seen.

Along these ridges find little pits. They are openings of ducts of sweat glands.

Frequently a minute drop of liquid will be seen standing in many of them.

Mark off a quarter of an inch square and count the number of these openings in its area, and from this estimate the number of glands in the palmar side of the hand and fingers.

Compare by means of a lens the surface of the back of the hand with that of the palm.

Thrust the hand and fore-arm into a large glass jar (a candy jar will answer) and close the mouth around the arm with a cloth. In a short time considerable moisture will form on the sides of the jar, as the result of the vapor thrown off.

To show the cooling power of evaporation, put a piece of thin cloth over the bulb of a thermometer and keep it moist with water, and note the change in temperature. Moisten the cloth with a few drops of gasoline or ether, and note the result.

Put a drop of gasoline or ether on the back of the hand, and observe the cooling effect.

Carefully examine the hairs, scales, claws, hoofs, and feathers of the common animals about us to see how they differ in form, what is their use, how they are attached, and other peculiarities, etc. This is a very profitable way to learn the many modifications which epidermis may undergo.

The kidneys of the rabbit can be studied at the time when the animal

is dissected for other purposes. They ought to be seen in place and in their proper relations.

For the study of the structure of the kidney that of a sheep or pig is excellent. A longitudinal section can be made and compared with Fig. 68 and the description given in connection with it. Its minute structure, of course, can only be made out with a good microscope with specially prepared sections of its substance.

Review Questions.

1. Give a general description of the skin.
2. What are its layers?
3. How is the epidermis formed?
4. What advantages result from its constant changes?
5. What are the functions of the epidermis?
6. Describe the structure of the dermis.
7. What organs does it hold?
8. Describe a papilla.
9. Where is the fat of the skin placed?
10. Where are the sebaceous glands, and what is their function?
11. What of the lymphatics?
12. What is the relation of the glands of the skin to the epidermis?
13. How does the arrangement illustrate the division of labor?
14. What are the functions of the dermis?
15. Name the three great excretory organs.
16. How great a secreting surface do the sweat glands possess?
17. How much do the sweat glands secrete a day?
18. In what two ways does the skin regulate the temperature of the body?
19. Illustrate cooling by evaporation and radiation from other objects.
20. How is the cooling apparatus in the body regulated?

21. What is said of the sensitiveness of the mechanism?

22. How is the skin an organ of special sense?

23. Sum up the functions of the skin.

24. Give the relation of a hair to the skin.

25. How does it grow?

26. Describe a nail.

27. What is its relation to the skin?

28. How does a nail grow?

29. What are its functions?

30. What are some of the modifications of the epidermis as shown in other vertebrates?

31. What of the importance of the skin as a whole?

32. What does the care of the skin require?

33. What are some of the dangers of lack of cleanliness?

34. What is the function of the kidneys?

35. How do they obtain the waste they secrete?

36. Where does the waste come from?

37. Describe the structure of the kidneys.

38. What is said of the nervous control of the secretion of the kidneys?

CHAPTER XVI.

THE HEAT OF THE BODY.

Animal Heat.—In the study of the skin it was shown how that organ is a great factor in the regulation of the temperature of the body, by increasing or decreasing its rate of cooling.

We have now to consider the method by which the body is heated. Enough heat must be furnished to keep the body at about 98° Fahr. the year round. As during almost the whole time the body is in an atmosphere whose temperature is less than that degree, and a considerable of the time much less, the heat required is considerable.

The Sources of Heat.—It has been shown that whenever a tissue cell is in the state of activity it takes in oxygen and throws off carbon dioxide; also, that it requires some food substance—that is, a substance which will combine with oxygen. It was further shown that one of the results of oxidation is the production of heat. Whenever any tissue is active, as muscular, glandular, or nervous tissue, one of the results of the activity is the production of heat. It may be stated, then, that one of the sources of heat to the body is from oxidations occurring in the tissue cells. Indeed, this is the main source.

There is at least one other source, although of much less importance than the one just mentioned. It is from the friction of the parts of the body on each other. If one, by muscular exertion, rub two pieces of wood together they will become warm. This heat of the wood is so much energy lost to the human body.

But when the heart pumps the blood-stream along, and the stream is checked in motion by resistance of the walls of the blood vessels, the loss of motion reappears in the body itself in the form of heat. The body by this means receives as much heat as it would take to run an engine big enough to pump the blood through the system. But even here the muscles of the heart are enabled to produce these motions by oxidations in their cells. Consequently, the ultimate source of energy in this case is also from oxidation.

Distribution of the Heat in the Body.—The activity of the tissue cells is at one time greater in one organ, at another time in another, but about the same temperature must be maintained throughout the body. This necessitates a method of equally distributing the heat through the body. The distribution is accomplished by the circulation of the blood, thus adding one other to its important list of functions.

To illustrate this method of distribution, let us suppose the digestive organs to be in a state of activity. Their glands in secreting, and the digestive juices in producing the chemical changes of which they are capable, give off a considerable amount of heat. The blood which circulates through these organs has its temperature raised. It is soon carried on and through all the other organs of the body, which, if cooler than the blood, are warmed by it. This could be illustrated by the activity of any other organ, such as the brain or the muscles of the arm.

Outside of the body a good illustration of this method of distributing heat may be found in the manner of heating buildings by steam or hot water. The heat is produced by oxidations in one room, the boiler-room, and is then distributed from this by means of the circulation of the steam or water through the pipes to all the rooms.

As the warming of the blood at one place tends to warm the whole body through its circulation, it follows that cooling it at one place will tend to cool the whole body. We experi-

ence this when we find that if the hands and feet are exposed on a cold day, the body is chilled, although it may be well clothed in other parts.

Regulation of the Production of Heat.—The body is not left to depend wholly on the oxidations which occur in the tissues when they are called into their special activity, or it would suffer when these are at rest, and could not adapt itself to rapid changes of the temperature of the atmosphere. It has the means through the nervous system of stimulating certain of the tissue cells to oxidation for the special purpose of the production of heat. As at this time the cells which are producing heat are not showing any other form of activity, it has not been definitely determined what tissues do this. But it is known that such action takes place. This nervous control acts just as do the other self-regulating mechanisms described for the control of the respiration, secretion of perspiration, and the like. It has a nerve center to which impulses come reporting the state of the body, whether above or below 98°, and from which nervous impulses go to increase or decrease oxidations for the production of heat.

Thus, by the regulating action of the skin in cooling the body, on the one hand, and by the regulating action of the heat-producing processes on the other, being nicely balanced, the very difficult problem of maintaining the body at a nearly constant degree through great changes of the temperature of the atmosphere is beautifully solved.

Disturbance of the Temperature-regulating Mechanisms.—When the delicate mechanisms just described are disturbed in their action, the balance between cooling and heat production is disturbed also. As a result the temperature of the body may be depressed, as is the case in the actions of the poisons *morphia* and *alcohol*, or the temperature may be raised in a small degree, as in slight inflammation, and in a large degree in extensive inflammations and in fevers.

More than a degree above or below 98° Fahr. is to be regarded as considerably away from the normal temperature, while as low as 96° or as high as 105° is an extremely dangerous condition of the body.

Clothing.—The body has the power to adapt itself to a considerable range between a scarcity and an abundance of clothing. It can survive much exposure. But the great strain on the heat-producing apparatus required by continued exposure has the same sort of objections to it as has the long-continued excessive exercise of the muscular, nervous, or digestive systems.

Excessive activity in the production of heat will interfere with other activities of the body, such as growth in the young, muscular or mental exertion in all. Constant exposure, instead of strengthening the body, as many suppose, really tends to weaken it, while comfortable clothing favors all the other forms of activity of the body.

Cold-blooded Animals.—This name is not well applied, as in such animals the blood may really be warm. They are animals whose temperature may vary within wide limits. It is generally very near the temperature of the medium in which they are living. For example, the blood of a frog may reach as low a degree as 32° Fahr. or go as high as 100°, a range of 68°.

In the **warm-blooded animals** a nearly constant temperature is maintained, and is necessary to their existence, the difference between the two being that in the warm-blooded animals the heat-producing and heat-regulating apparatus are well developed, while such is not the case with the cold-blooded animals.

During the *hibernation* of certain warm-blooded animals, they for the time are somewhat like cold-blooded animals.

Review Questions.

1. What is the temperature of the body?
2. What is the range of the temperature of the atmosphere?
3. What is the main source of the heat of the body?
4. Name and explain one other source of heat.
5. How is heat distributed through the body?
6. What would be the effect on the whole body of heating or cooling a single part? Explain.
7. Illustrate these by description of similar contrivances used outside of the body.
8. How is the production of the heat regulated?
9. How do the heat-producing process and the cooling process work together?
10. What is said of clothing?
11. What are cold-blooded animals?
12. How do they differ from warm-blooded ones?
13. What is hibernation?

CHAPTER XVII.

THE ANATOMY OF THE NERVOUS SYSTEM.

Structure of the Nervous Tissues.—*Gray Matter and White Matter.*—To the naked eye the nerves appear as white cords of varying size, rather firm to the touch, but not so strong as the tendons. The substance of the brain is soft, easily torn, and shows a thin coating of light "gray matter" on the surface and in small masses at its base, with considerable "white matter" intervening. The spinal cord is composed of the same substances, with the white matter enveloping the gray.

This "white matter" and "gray matter," as they appear to the naked eye, are structureless masses, but this is far from being the case, as they consist of an extremely delicate and definite structure.

Structure of the Nerve Tissue.—The study of the tissues of the nervous system with the microscope shows the white matter to be composed of the *nerve fibers*, and the gray matter of *nerve cells*. These are bound up in masses by connective tissue. It is very important to a clear understanding of the physiology of the nervous system to get as clear conceptions as possible of these elements.

The Nerve Cell.—The nerve cell is a mass of protoplasm with a plainly seen nucleus, and the cells from different parts of the nervous system have different shapes. Fig. 69 shows some of these. Some nerve cells are so large as to be seen with even a low power of the microscope. Most nerve cells are irregular in shape and have processes extending from the surfaces. In most fully developed nerve

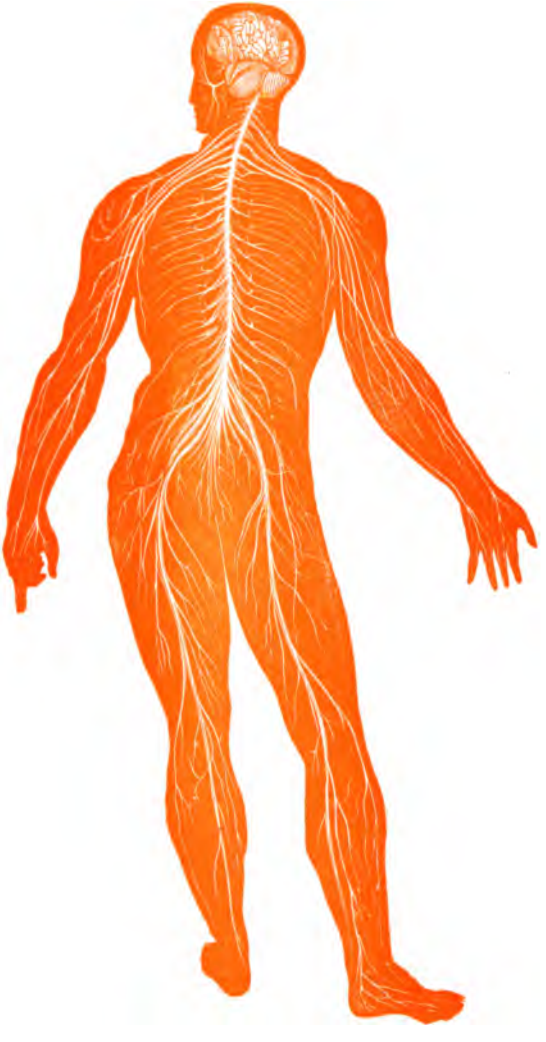


Fig. 69.

GENERAL VIEW OF NERVOUS SYSTEM.

AD.—209

cells one of these processes is very greatly extended as a

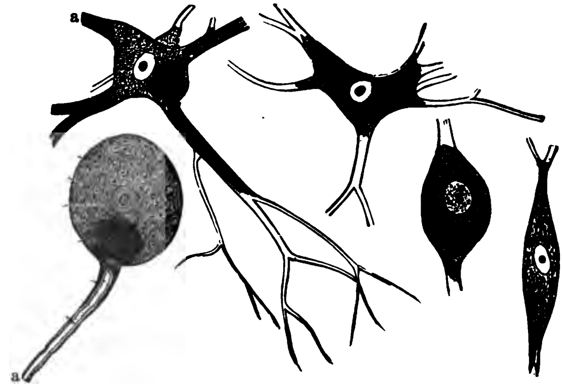


Fig. 70.

FORMS OF NERVE CELLS.

a, axis cylinder of a nerve fiber (magnified).

thin thread of protoplasm, which becomes the core of the *nerve fiber*. (Figs. 70 and 72.)

The Nerve Fiber.—Every nerve fiber has this core—

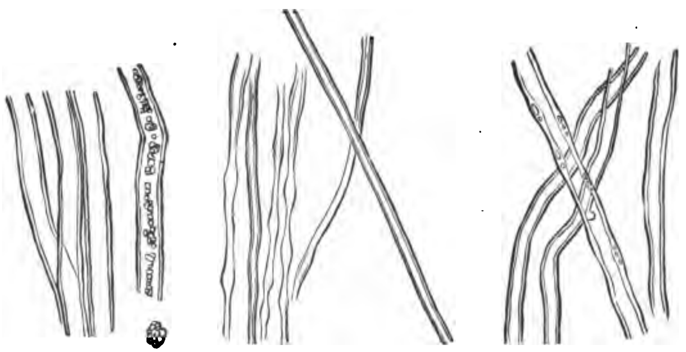


Fig. 71.

NERVE FIBERS AS THEY APPEAR SHORTLY AFTER TAKEN FROM THE FRESH NERVE (MAGNIFIED).

called the *axis cylinder*—which is always the prolongation of

the protoplasm of the nerve cell. In most nerve fibers this central thread of protoplasm becomes covered with certain coats, which protect and nourish it, and probably act in the same manner as the insulation substances with which wires used to conduct electricity are sometimes coated. In most fibers these coats are two in number: an outside one, forming a tube, the *primitive sheath;* and between the walls of this tube and the central thread is a coat of an oily, semi-liquid substance, called the *medullary sheath.* These three parts together constitute the *nerve fiber.*

The nerve fiber is, of course, microscopic, being from $\frac{1}{12000}$ to $\frac{1}{1500}$ of an inch in diameter, and may be some feet in length. While a single nerve cell or a single nerve fiber would appear nearly colorless and semi-transparent under the microscope, yet, seen in groups, the nerve cells are a yellowish-gray in color, and the fibers are white; hence the terms often applied to them, the "gray matter" and the "white matter." If we use these terms we must not allow their use to make us forget the real structure of the *gray matter* and the *white matter.*

A Nerve Ganglion.—The nerve cells rarely exist singly, but are gathered together into groups of greater or less size. One such group of nerve cells is called a *ganglion.* Ganglia are found scattered through many parts of the body, or gathered into large masses, as in the *brain* and in the *spinal cord*, to be more fully described presently.

The Structure of a Nerve.—The nerve fibers, with the connective tissue which binds them together, form the nerves.

A nerve consists of a bundle of nerve fibers bound together by connective tissue; these small bundles are bound together into larger ones, the whole group surrounded by a sheath of connective tissue, called the *perineurium*, the whole making a white cord. The largest in the human body is the *sciatic nerve*, located in the thigh, which is as thick or thicker

than an ordinary lead pencil. These larger nerves contain many thousands of the nerve fibers described above.

A nerve has, beside these parts, its own blood vessels and nerves, for maintaining its nutrition.

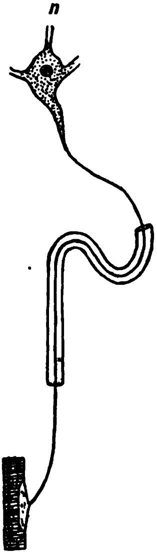


Fig. 72.

DIAGRAM SHOWING THE RELATIONS OF A NERVE FIBER TO A NERVE CELL AND A MUSCLE CELL. (E. H.)

The line is the *axis cylinder;* the tube is the *primitive sheath*, removed for most of the way; *m*, muscle cell; *n*, nerve cell.

How the Nerve Fibers Terminate.—Now, if we could trace toward the central axis the course of the various nerve fibers in a nerve like the sciatic, for example, we would find that every one of the thousands of nerve fibers, without exception, ends in a nerve cell in the spinal cord, the brain, or in some of the ganglia outside of these.

If we should trace these same fibers in the opposite direction, they would be found to end differently. Some penetrate the muscles, where they spread out and finally end in the *muscle cells.* Others follow the blood vessels and end in the muscle fibers of their walls. Others would seek out the *gland cells* where they terminate. Still others pass on to the skin, where they are found to terminate at the roots of the hairs, or in curiously formed groups of cells, called the *touch corpuscles.*

In other parts of the body than the organs mentioned, the nerve fibers would be found to end in various other forms of special sense cells, as those of the *retina* (sight cells), or in the *auditory cells*, *olfactory cells*, and *taste cells;* or they may have several other specially formed cells for their endings. In the brain and spinal cord the nerve cells are also connected with one another by nerve fibers in a very complex way.

Efferent, Afferent, and Commissural Fibers.—Fibers

which connect a nerve center with muscles or glands are called *efferent*, or *motor* fibers; those which connect nerve centers with sense organs are named *afferent*, or *sensory* fibers; and those which connect nerve cells with nerve cells are known as *commissural* fibers.

Summary of Distribution.—To sum up, then: Each of these nerve fibers in a nerve ends centrally in a nerve cell, and outwardly in either a muscle cell, gland cell, or sense-organ cell. And, further, in the nerve centers cells are connected with cells.

Gross Anatomy of the Nervous System.—Having seen clearly the elements of the nervous tissues, we may next consider how these elements are gathered up into definite masses and tracts, and distributed in a grand system. Let us bear in mind that, however complicated it may be, its elements are *nerve* fiber and *nerve* cell.

The nervous tissues are arranged in a great system which pushes its parts into almost every portion of the human body. Its great importance in the activity of the body and the connection it has with our means of gaining knowledge and of thinking, make it a matter of great interest to know its exact position in the body, and its relation to the other parts.

A careful examination of the nervous system of some animal small enough to be conveniently handled—for which purpose none is better than a frog or a cat—will be of greater aid than any description or chart alone could be. This dissection, however, to have such value, should be done well enough to show clearly all the parts as far as they can be seen well with the naked eye.

The nervous system is regarded as divided into two general divisions:

The *Cerebro-spinal System* and *the Sympathetic System.*

The **Cerebro-spinal System** consists of a large axial portion, the *brain* and *spinal cord*, which is inclosed in the

axial skeleton, and forty-three pairs of nerves, which branch from this axis: twelve pairs from the brain, *cranial nerves*, and thirty-one pairs from the spinal cord, *spinal nerves*.

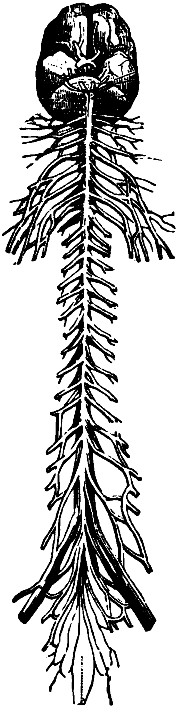


Fig. 73.
CEREBRO-SPINAL AXIS.

These forty-three pairs of nerves are white cords of considerable size, composed of thousands of minute nerve fibers. These nerves run out from the spinal cord, giving off, as they go, branches as smaller nerves; these again subdivide, until they reach the various organs of the body into which they enter, and in their tissues continue their subdivision until the branches are so small that they can not be seen by the naked eye, and at last the fibers are distributed among the ultimate cells of the tissues in the organs.

Spinal Nerves.—The spinal nerves are connected with the spinal cord by two roots, one from the anterior side of the cord, the *anterior root;* the other from the posterior side, the *posterior root.* Each root arises by several rootlets (Fig. 74). On the posterior root, near the point where it joins the anterior root, is a little knot of nervous matter called a *ganglion.*

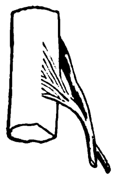


Fig. 74.
SHOWING THE TWO ROOTS OF A SPINAL NERVE.

Cranial Nerves.—The cranial nerves arise from the brain as shown in Fig. 75. They pass through openings in the cranium, and are distributed as follows:

The first, the *olfactory*, to the membranes of the nasal passages.

The second, the *optic*, ends in the retina of the eye.

The third, fourth, and sixth, *motor* nerves, go to the muscles of the eye.

The fifth, the *trigeminal*, is a very large nerve. It is distributed to the skin of the face, to the muscles moving the jaws, and furnishes sensory nerves to the front part of the tongue (gustatory).

The seventh, or *facial*, to muscles of the face.

The eighth, the *auditory nerve*, to the internal ear.

The ninth, the *glossopharyngeal*, partly to the tongue as nerves of taste, and partly to the muscles of the pharynx.

The tenth, the *pneumogastric* or *vagus*, to the larynx, lungs, liver, stomach, and breast, and is mainly sensory and inhibitory.

The eleventh, *the spinal accessory*, to muscles of the neck.

The twelfth, *the hypoglossal*, to the muscles of the tongue.

All those nerves which join the brain and spinal cord so distribute their fibers in these organs that they finally end centrally in their nerve cells. Thus, the cells of the other tissues of the body are connected with the nerve cells of the brain and spinal cord, as has been before shown.

Membranes of the Brain and Spinal Cord.—The brain and spinal cord, as they lie in their bony canal, consisting of the skull and the upper part of the spinal column, are covered over with three membranes formed of connective tissue. The first, or outer coat, is a very dense, tough one, the *dura mater*. It holds the parts firmly in the bony canal. The inner membrane, the *pia mater*, is applied directly to the brain and spinal cord, and is of delicate texture. It carries a great number of blood vessels, which, branching out from it by a fine network, penetrate the nervous tissues and furnish them with an abundant supply of blood.

The middle coat, the *arachnoid membrane*, is of a very loose texture, its middle portion containing large spaces filled with a serous watery liquid, by which means the brain and spinal cord may be said to have a watery cushion cover-

ing them and tending to equalize any pressure which may b applied at any point on their surface.

The membranes are sometimes called in anatomy the *cerebro-spinal meninges*, and an inflammation of them constitutes a very dangerous disease called *cerebro-spinal meningitis*.

The dura mater and pia mater are continuous with the sheaths of the nerves which leave the brain and spinal cord.

Blood Vessels and Nerves of the Brain and Spinal Cord.—The brain, spinal cord, and nerves, at least the large nerves, have their own blood vessels and nerves distributed to them, as do the other tissues of the body.

The Spinal Cord.—The spinal cord is that part of the nervous axis which extends from the *foramen magnum* in the occipital bone down to about the second lumbar vertebra. (See Spinal Column.) It is about as thick as one's little finger, and eighteen or twenty inches in length.

The end of a portion cut across would show that it is a double organ, the two halves being united by a small portion in the center. The cut end would show an H-shaped grayish central portion, the parts around it being white. This gray portion is composed of immense numbers of nerve cells, among which run many fibers. The white portions are the cut ends of multitudes of nerve fibers which are going to lower or higher parts of the spinal cord, or to the brain. The white part of the spinal cord may be considered as a large nerve, the gray core as a series of ganglia.

The Brain.—The brain (Figs. 75, 76) is that portion of the nervous system which is encased in the skull. A study of its development shows that it may be considered as the anterior end of the spinal cord immensely developed and specialized. It consists of a *fore-brain*, a *mid-brain*, and *hind-brain*.

The Cerebrum.—The fore-brain consists of the large portion in front called the *cerebrum*.

The cerebrum is made up of two *hemispheres—right* and *left*—separated from each other by a deep fissure, at the bottom of which the two halves are connected by large nerv-

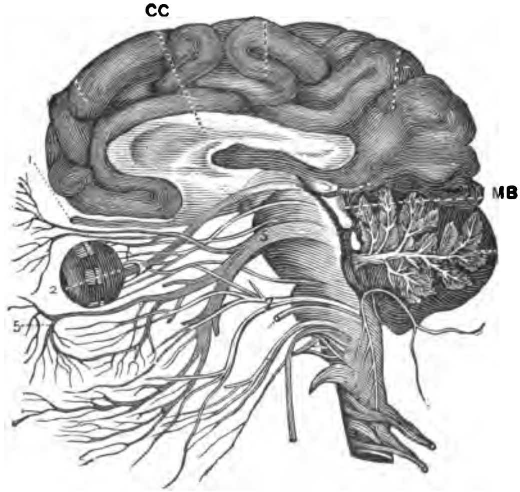


Fig. 75.

VERTICAL SECTION OF BRAIN.

The upper part is the cerebrum; the part to which the nerves, except the two lowest, are connected, is the *medulla*. The part with tree-shaped figure is a section of the cerebellum. *CC*, corpus callosum; *MB*, mid-brain. The two lowest are spinal nerves; the other nerves are the cranial nerves, which are known in the order of their origins from above down. Their names are given in the text.

ous masses, the most conspicuous of which is the *corpus callosum.* (See Fig. 75, *CC.*)

Convolutions.—The surface of the cerebrum is covered with many winding ridges called convolutions, a means by which the surface of the brain is increased to about four square feet.

Cerebral Ganglia.—At the base of the hemispheres are several paired masses of nervous matter, the largest of which are (Fig. 85) two—one lying somewhat in front, the *corpus striatum;* the other a little back of this pair, the *optic thalamus.*

The Mid-brain.—The mid-brain consists of two pairs of ganglia, just back of the cerebral ganglia, known as the *corpora quadrigemina.*

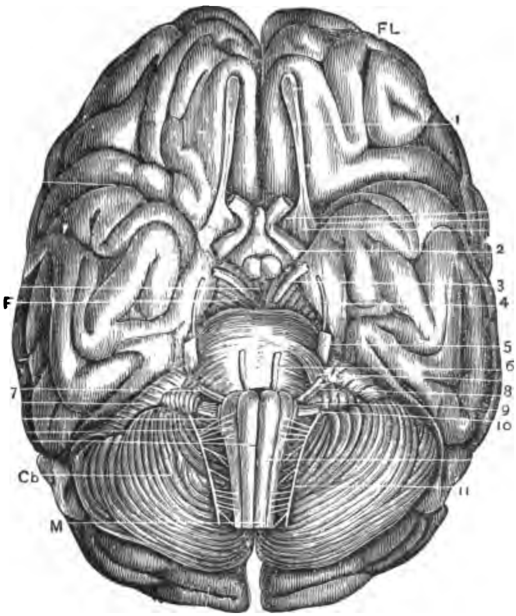


Fig. 78.

VIEW OF THE BASE OF THE BRAIN.

FL, frontal lobe of cerebrum; *M*, medulla; *Cb*, cerebellum; *F*, mass of white fibers running from medulla to cerebrum, called *crura cerebri*. Between *F* and the root of 7 is the *pons Varolii*, bands of fibers going to the cerebellum. The numbers refer to the roots of the cranial nerves, as given in the text.

The Hind-brain.—The hind-brain is composed of the *medulla oblongata* and the *cerebellum.*

The *medulla oblongata* is continuous with the spinal cord below and with the mid-brain and cerebrum above.

The *cerebellum* is a large mass which is borne on the back of the medulla oblongata, and is immediately connected with it. It is covered with numerous parallel ridges, which answer somewhat to the convolutions of the cerebrum, and are a means of increasing the surface of the gray matter which covers it.

The Arrangement of the Gray and White Matter in the Parts of the Brain.—*The gray matter*—that is, the nerve cells—in the cerebrum makes a layer over the *sur-*

face of the convolutions about an eighth of an inch thick. This layer follows the convolutions of the brain closely through all its foldings, even down into the mass of the cerebrum. Large quantities of gray matter are also found in the ganglia at the base of the cerebrum, the *optic thalamus*, and the *corpus striatum*. In the *mid-brain* there is a considerable amount of gray matter all through the ganglia.

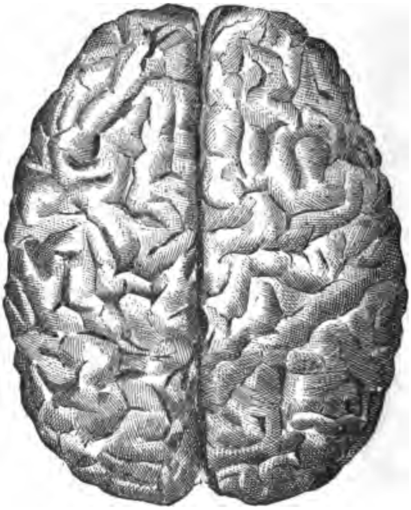


Fig. 77.
BRAIN SEEN FROM ABOVE.

In the *medulla* it forms several groups and bands. In the *cerebellum*, as in the cerebrum, it forms the thin outer layer on the surface of the *convolutions*, and also makes up *ganglia* deeper in its masses.

The *white matter* occupies the other portions of these parts. It is necessary to remember constantly that the white matter is composed of fibers. These fibers in the cerebrum—

1. Connect the cells of convolutions on one hemisphere with those on the other.
2. Some of those of the same hemisphere with their neighbors.
3. Those of the convolutions with those of the ganglia at the base of the cerebrum.
4. Others connect cells of the hemispheres with nerve cells, either of the medulla, cerebellum, or spinal cord, and possibly they have other connections.

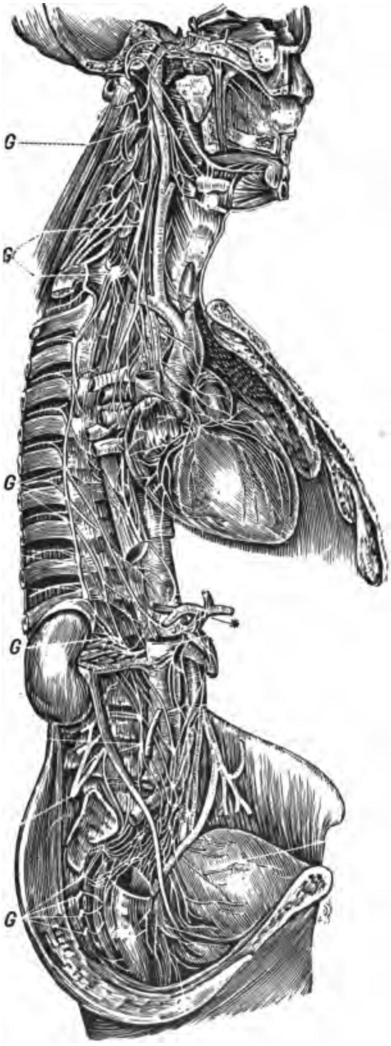


Fig. 78.

GENERAL VIEW OF THE SYMPATHETIC SYSTEM. *G G G*, etc., chain ganglia on one side.

The *white matter of the medulla* is large in amount, and consists of the fibers which pass to the brain from below or *vice versa*, of those passing to the cerebellum, and of those originating in the medulla.

In like manner, the *white matter of the cerebellum* consists of great bands of fibers connecting its layer of surface gray matter and its ganglia with the cells of the cerebrum, medulla, and spinal cord.

Some white matter in these are the fibers that these parts send out to, or receive from, still other parts of the body.

The Sympathetic System.—The *Sympathetic System* consists of a number of little *ganglia* distributed through the body, which give origin to a very complicated *network of nerves* which are distributed to all the viscera and to the muscle cells in the coats of the arteries.

The main *ganglia* of this system are arranged in two chains, which are in front and a little to each side of the spinal column. Each ganglion is connected with its neighbors by *commissural nerves*, and with the nearest spinal nerve close to the point where it leaves the spinal cord.

Besides these chains of ganglia, many other sympathetic ganglia exist in other parts; for example, there are several in the heart. The name "sympathetic" is not to be taken as indicating any special function distinguishing it from the cerebro-spinal system. The latter system is for the purpose of bringing distant parts into relation or "sympathy" as well. Indeed, it is known that the cerebro-spinal system furnishes a large part of the fibers which run in the sympathetic system.

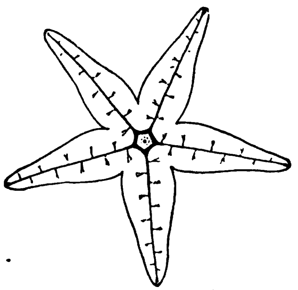


Fig. 79.

Nervous System of a Star-fish. (From the object by E. H.)

There is still doubt as to the real nature of the functions of many of the sympathetic ganglia.

Comparisons with Nervous Systems of Lower Animals.—For comparison it would be very profitable as well as interesting to examine the nervous systems of some of the lower animals.

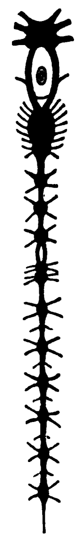


Fig. 80.

Nervous System of a Crawfish. (From Lang.)

Fig. 79 shows a sketch of the nervous system of a star-fish, which consists of ridges of cells hardly to be separated into ganglionic cells and nerve fibers.

The nervous system of a fresh-water mussel consists of three pairs of ganglia, with connecting nerves and nerves for the distribution to other parts of the body.

Fig. 80 is that of a crawfish. Here we have a row of gan-

glia with its nerves. That of a fly (Fig. 81) is much on the same plan.

Among the vertebrates, the nervous system is for the most part on the same plan as in man, the greatest difference among them being in the development of the brain, especially the cerebrum, which in man reaches its highest development.

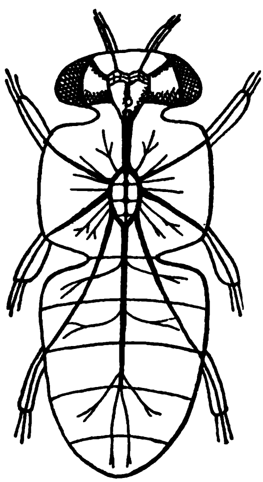


Fig. 81.

NERVOUS SYSTEM OF A FLY. (From Lang.)

It is very instructive to prepare brains of a fish, a frog, a bird, a dog, and a cow, to compare with the figure of the brain of a man.

Directions for Practical Work.

To understand the distribution of the nervous system it is very desirable that a careful dissection of the nervous system of some animal be made. This is easiest done in the frog or toad.

A somewhat larger animal, while it requires more trouble, is more satisfactory. A chicken, a rabbit, or a cat is generally the most available.

The animal should be fastened as in other dissections, the viscera all removed, and the body made clean. The skin should be removed only so far as is necessary to expose the parts to be examined, and then in such a way as to allow laying it back again over the parts.

The chain of ganglia of the *sympathetic system* may be found in the same position and of the same form as shown in *G G G*, etc., in Fig. 78.

This, as well as every dissection, requires care, patience, and intelligence. Many beginners cut everything to pieces and confuse the whole before having a chance to see any thing. One might as well hammer a watch to pieces and then try to make out its parts.

When one ganglion is discovered, by tracing out its nervous connections others will be found, and the majority can be made out. Many of the nerves were removed with the viscera.

For the *cerebro-spinal system*, one may begin by separating the muscles

of the fore leg until he comes upon a nerve, which may be easily distinguished from a tendon or the blood vessels by the knowledge gained of these organs in the former study of their form and connections

Having found a nerve, trace it toward the spinal column, taking care not to cut or break it. Indeed, cut only what is necessary to expose the nerve.

By following this nerve, it will soon be found to be connected with a network of nerves, the individual ones of which if traced up to the backbone on one side and toward the foot on the other, will lay bare the nervous system of the leg.

It may then be seen how some nerves go to the muscles and some to the skin, and how all come from the spinal cord.

The same methods may be pursued with the hind leg with similar results.

If one desires to learn the names of the nerves, he will find that as they closely correspond in distribution to those of the human body, any of the works on human anatomy, some of which are accessible in every community, will contain the names and complete descriptions of their distribution.

To remove the parts and expose the brain and spinal cord is a more difficult task. It is a matter of sawing and breaking the bone by means of nippers, and of patiently cutting away the flesh.

The brain in so small an animal as a rabbit can be taken out without much trouble, and it is still easier to remove the brain of a chicken.

It is desirable to study the brain of a larger animal, for which that of a sheep is perhaps the best and most easily obtained. It is best to examine one brain fresh, and place another in alcohol for a few days, so that it will become hardened sufficiently to allow of dissection. The fresh brain is so soft that it can not be dissected in detail. The alcohol should be of three or four times the amount of the brain, and the brain so placed in it that the alcohol may be in contact with its whole surface.

Refer to the figures in the book for the names and parts of the brain, as these brains are on the same plan as that of the human brain.

If the attempt to expose the spinal cord is a failure by the method given above, the whole spinal column may be sawed in two, lengthwise, as the butcher does the beef. This may be done so as to leave a large part of the cord still in its cavity. This will afford a means of seeing its relations to the spinal canal, its coats, and many of the roots of the nerves.

This section also shows the arrangement of the vertebræ and the way they articulate. Indeed, on any day one can see at a butcher shop a beautiful section of this whole arrangement, made without any trouble or expense to himself.

For microscopic examination of nerve fibers, those of a frog or toad can be examined with but little more trouble than by teasing the fibers apart in water slightly salt or in saliva. If well separated, the fibers will appear somewhat as in Fig. 70.

But to show the complete structure of nerve fibers and of nerve cells will require more special histological methods. A few prepared slides are very valuable in making the subject clear.

Review Questions.

1. Describe the naked eye appearance of nervous tissues.
2. Of what is the gray and of what the white matter composed?
3. Describe a nerve cell.
4. What is the relation of a nerve cell to a nerve fiber?
5. What are the parts of a nerve fiber?
6. Which of these is the essential part?
7. Describe the structure of a ganglion.
8. Explain the structure of a nerve.
9. How large are nerves?
10. What is the true relation of the nerve fiber to the nerve?
11. How do the nerve fibers terminate centrally?
12. With what are the outer ends of the nerve fibers connected?
13. What part of the nerve fiber is actually connected with the cells in which it terminates?
14. What are afferent nerve fibers? What are efferent nerve fibers? Commissural fibers?
15. Draw a diagram to illustrate a nerve fiber and its connections.
16. What are the great divisions of the nervous system?
17. Of what does the cerebro-spinal system consist?
18. What is a spinal nerve?
19. What is a cranial nerve?
20. Point out in Fig. 75 the cranial nerves.

21. What are the coverings of the brain?

22. How are they arranged?

23. What of the coverings of the spinal cord?

24. What of the blood supply to the nervous system?

25. What is the position of the spinal cord?

26. Describe its form and structure.

27. What are the main divisions of the brain?

28. Describe the cerebrum.

29. What are the convolutions?

30. Where are the *optic thalami* and the *corpora striata?*

31. Locate the mid-brain.

32. Of what is the hind-brain composed?

33. Describe each part.

34. Give the arrangement of the gray and white matter in each of the parts of the brain.

35. What parts do the fibers connect?

36. Of what is the sympathetic system composed?

37. What is the distribution of its parts?

38. Compare the nervous systems of some of the lower animals with that of man.

CHAPTER XVIII.

THE PHYSIOLOGY OF THE NERVOUS SYSTEM.

Function of the Nervous System in General.—The main use of the nervous system in those animals which possess it is to serve as a means of communication between the various groups of cells in the different parts of the body, and to put it in communication with the external world. It is only by communication of some kind that things at a distance from each other can act in concert.

For example, the sight of a coin on the road may lead us to pick it up. But in order that such an action may be brought about, the cells in the eye which are affected by the light from the shining coin must be in communication either directly or indirectly with the cells of the muscles which are stimulated to contract to produce the act mentioned.

This act is itself a very complex one. The picking up of the coin employs not one muscle alone, but many—indeed, very many; it may be the majority of those in the arms, legs, trunk, head, and neck. These different groups must alternately contract and relax in just sufficient amounts to produce all the particular flexions and extensions necessary for this complex act.

That the body may arrive at the proper position, and that the hand may strike just the right point, the eye must look again and again; this involves other sets of motions of the eye itself and the formation of judgments by which the various acts employed are guided. Other parts of the body, such as the heart and the respiratory muscles, would also have to modify their action somewhat to suit this case.

of individuals, living together and beginning to make a division of the labor of the community for their own advantage, are compelled to communicate with each other.

If the community is small, each one may carry his own message, and the work go on pretty well; but when the community is divided up into many parts, which are scattered over larger areas, then there spring up special systems of communication, and commissions to manage and make the best use of all the knowledge which comes to each.

This state of affairs gives rise to the many forms of communication, and demands that a part of the community devote their whole time to this special business.

Among the lower animals, those called protozoa (Fig. 5) are like the man living alone; the hydra, with its groups of cells, each cell passing the impulses it receives to its neighbor cells, and these to the next, is represented by the small community; while one of the higher animals, with its immense groups of cells scattered at great distances, is paralleled by a great nation, like our own, with its intricate systems of communication by wire, railroad, steamboat, stage, and messenger, employing for this work exclusively a vast army of men and much capital.

Properties of Nerve Tissues.—The action of the whole nervous system, like the action of any other kind of mechanism, depends upon the properties of its elements and the manner in which they are connected, each of which we may now study in more detail.

The Property of the Nerve Fiber.—The nerve fiber is so composed that it has a better developed power of conduction than that possessed by any other substance in the body. The impulses which it can conduct start from either of two sources:

1. From some sense-organ cell, in which case the impulse is transmitted by the nerve fiber to a nerve cell in the nerve center;

2. From a nerve cell in a nerve center. In this case, of course, the impulse is conducted either outward to some muscle cell or gland cell, or it may be conducted to another nerve cell in that, or a distant, nerve center.

The "conduction" depends on the fact that the protoplasm (living substance) of the sense-organ cell is continuous with the protoplasmic thread core of the nerve fiber. This is again continuous with the protoplasm of the nerve cell of the nerve center.

This protoplasmic thread, traced in the opposite direction, comes to the muscle fiber, as we have seen; and its protoplasm touches that of the muscle cell. Thus we have a continuous protoplasmic path from the sense-organ cell through the nerve center to the muscle cell.

Property of a Nerve Cell.—The nerve cell differs from the other tissue cells in being extremely sensitive to the impulses brought to it by nerve fibers. The chemical composition of its protoplasm will change by the slightest stimulus.

In the mechanical arts, we make use of chemicals which will readily decompose and produce a vast amount of energy of another kind (mechanical) by means of a small stimulus. Examples such as gunpowder, dynamite, explosive mixtures of many kinds, may be named.

In the animal body, nerve cells are similar to these substances, with the exception that they, when stimulated, give rise to large amounts of nervous impulses instead of an explosion. The explosives are used to blow up stumps, split rocks, throw bullets, or run machinery (gas engines); but in the body the nerve cells are caused to give out nervous energy to contract muscles.

The function of these nerve cells, then, is to be sensitive to impulses from without, or to changed conditions within themselves; and, answering to these stimuli, to discharge with

increased energy these impulses down their natural conductors—the nerve fibers—to muscle cells and glands.

These relations may be made clearer by the study of the diagrams represented in the following figures. In Fig. 82 we have the simplest arrangement. Let us study how this apparatus may act. If we may press upon the sense-organ cell, *S*, in the figure—an apparatus so adapted as to be irritated by such pressure—this irritation sets up a series of changes which are conducted along the core of the afferent nerve fiber; these arrive quickly at the nerve-center cell, *N*.

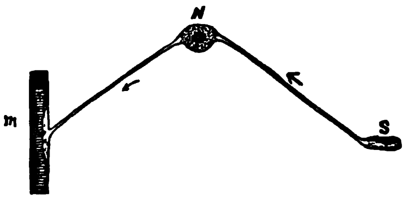


Fig. 82.

DIAGRAM OF A SIMPLE NERVOUS MECHANISM.

S, sense-organ cell; *N*, nerve-center cell; *M*, muscle cell. On the right is an afferent nerve fiber, on the left an efferent nerve fiber.

This is composed of chemical substances which are readily affected by this little impulse; as a result, it discharges a stimulus down the only outlet to its energy, the core of the other (efferent) nerve. This brings this impulse finally, with a shock, to the protoplasm of the muscle cell, *M*.

By this piece of mechanism, then, with its five parts, each with its own peculiar property, a motion at one place could be produced by a pressure at another place.

Nature of a Nervous Impulse.—The nature of the impulse that passes along the nerve fiber has been the subject of much speculation among physiologists. The form of the apparatus and its apparent mode of conduction has suggested to many that it is an electrical current. However, it seems to be pretty clearly proved that it is not electricity. Still, it is probable that it is some form of molecular motion conditioned by the peculiar form of the molecule of living nerve substance.

The nerve is not a good conductor of electricity, and the

velocity of the nervous impulse—about one hundred feet per second—is very much slower than that of electricity.

Comparison of Nervous Mechanisms to Mechanical Inventions.—Man has invented many pieces of apparatus which perform different kinds of actions by touching a button, a knob, or lever, which can be compared in many ways to this simple mechanism in the body.

Increase of Number of Elements.—Now we can make our mechanism much more complex by increasing slightly the number of elements. In Fig. 83, the diagram represents the former one several times repeated and connected. In this group are nine nerve cells, which may represent a nerve center or ganglion. They are connected with each other by nerve fibers, and also with muscle cells (*M*), and with gland cells (*G*), and with sense-organ cells. The arrows indicate the direction of the impulses, whether efferent or afferent.

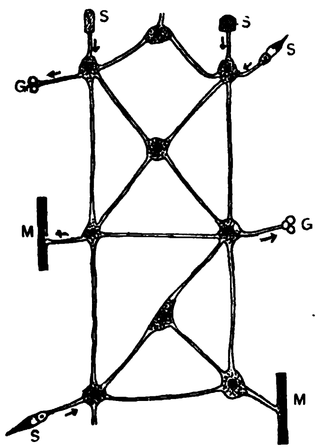


Fig. 83.

A COMPLEX NERVOUS MECHANISM.

S, sense-organ cells; *G*, gland cells; *M*, muscle cells.

Now, it is easy to see that an impulse coming from any cell marked *S* might affect several muscles; or, if impulses should soon follow from one of the other cells marked *S*, or from some other source, or from them all at the same time, the result on the muscles and glands would be hard to predict. It can easily be seen that it would be the result of what the nerve cells would make of so many stimuli, and that the result would depend much on the way they were connected.

Now, if we should immensely increase the number of the elements represented in these diagrams, and then gather together the nerve cells into the gray matter of the brain, spinal cord, and ganglia, and the fibers into groups, having their outer ends connected with the muscle cells and gland cells, and their inner ends with the nerve cells, we should have our nervous system. Thus we see that it is a very complex mechanism.

Or, to put it another way, if we could separate all the nerve cells and fibers in the nervous system without breaking any of their connections, and then magnify the whole very much, there would be represented to us for every nerve leaving the brain or spinal cord thousands of fibers finding every muscle cell, gland cell, and sense-organ cell in the body. In the opposite way, they would be seen to end in millions of nerve cells, which would again be connected with each other in such an intricate way as to confuse us with its complexity.

Definite Plan in this Complexity.—But with all this complexity there is no confusion in the working of this mechanism. The connections are so perfect that if certain sense-organ cells on the hand are touched with a hot wire, just the right muscles contract to pull the hand away. When the light from a shining coin comes to the eye, just the proper sets of muscles can be brought into use to pick it up.

Nerve Stimuli.—By studying the muscle and nerve in a frog's leg, as described before, physiologists have learned some interesting facts about the nerve. Its natural stimuli are impulses starting from the changes in nerve cells. But a hot wire applied to the end of a nerve will make the muscle contract; so, also, will certain chemicals, or a pinch (mechanical stimulus), or electricity. Thus, these are stimuli for nerves as well as for muscles. (See the chapter on Muscles.)

Velocity of Nervous Impulses.—The velocity with which a nervous impulse travels along a nerve has been measured and found to vary somewhat with the conditions

of the nerve, but it is about one hundred feet per second, which is no faster than a railroad train sometimes moves. Since our nerves, even the longest, are but a few feet in length, the passage of the impulses seems instantaneous; yet if we had a nerve about seventy miles long, it would be an hour after injury received at the outer end before it could be felt in the brain.

Conditions affecting the Activity of a Nerve.—Like the muscle, the activity of the nerve is quickly affected by cold or heat, overwork, lack of oxygen, or lack of nutrition. What is true of the nerve fibers is more emphatically true of nerve cells. That they may be properly active they must be constantly invigorated with good blood—that is, blood with plenty of oxygen and food supply; and they must have the carbon dioxide and their other waste products rapidly removed.

If the artery taking blood to the brain be compressed for only a moment, it will cause fainting; this continued will cause death. If the blood supply to any other part of the nervous system is withheld for a short time, most serious results are brought about.

Reflex Actions.—An act performed by such a simple mechanism as represented in Fig. 82 is a *simple reflex action;* one performed by the nervous apparatus, described in Fig. 83, is also a *reflex action*, but a more complex one. A reflex center is distinguished by the fact that it acts only on receiving an impulse from without. The group of cells taking part in it is a *reflex center*. A *reflex center* is one which will send out impulses when it receives a stimulus from the sensory nerves coming into it. It is easy to find reflex actions among the movements of our bodies. If one accidentally touches the hot stove with the hand, it is instantly drawn away. This is done by a reflex center in the spinal cord.

Nerve fibers connected with the heated cells in the skin carry the impulses thus formed up the nerves of the arm to

the spinal cord, where they stir up a group of sensitive nerve cells to action. This immediately discharges an impulse down another set of fibers to certain muscles of the arm, which jerk the hand away.

Now, this reflex center would do this even if it were disconnected from the brain. Persons have, by a fall, or by means of a bullet, or in some other way, received such a severe injury as to cut off the lower part of the spinal cord from the upper part, and through this from the brain.

When the foot of a person so affected is burned or pinched, the muscles move the leg just as they would with the uninjured spinal cord. In the uninjured cord, not only does the reflex center receive the impulse from the burn and send out impulses to muscles to produce this reflex action, but it also allows impulses to travel on up to the centers in the brain, by which consciousness of the pain may be produced.

If the head of a frog be cut off, the legs may be made to kick quite naturally by touching them. If a drop of irritating liquid is placed on the skin of its back, it may be made to scratch that point, first with one hind foot, and then, if the irritating liquid is not removed, with the other foot, or with both feet. All of the nervous system that is left with which to accomplish these actions are the spinal cord and its nerves.

In like manner, a turtle with its head severed from its body may be made to swim, crawl, and perform many complex acts. No more familiar example of the bodies of animals showing activity even when the body is separated from the brain could be mentioned than that of the violent ones of a chicken immediately following the cutting off of its head. Such examples could be greatly multiplied, but these will answer our purpose.

The fact should be emphasized that in these cases it is the spinal cord that executes these motions, and does so only when stimuli come to it from without. In these cases, if the

turtle or chicken were in no way touched, it would give no motions.

Many careful investigations have shown that the gray matter of the spinal cord is for the most part a series of reflex centers. It may be said that *one* of its *chief functions* is that of *reflex action.*

These reflex actions may be so complex that it is hard to believe, when watching them take place, that they are not governed by intelligence in the decapitated animal, yet they are clearly only the result of the action of a very nicely adjusted piece of complex machinery.

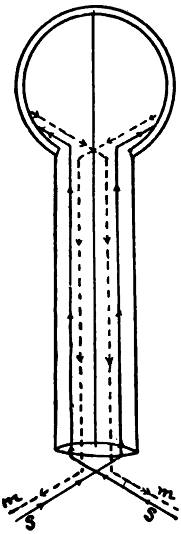


Fig. 84.

DIAGRAM TO SHOW COURSE OF NERVE FIBERS IN THE SPINAL CORD.

M, motor, and *S*, sensory, fibers.

Spinal Cord as a Conductor of Impulses.—The other function of the spinal cord is that it acts as a *conductor* of the impulses from the brain downward to the motor nerves, and from the sensory nerves from below up to the brain.

Course of the Fibers in the Cord.—The motor fibers which enter the cord by the anterior roots of the spinal nerves on the right side ascend to the brain on the right side of the cord, and seem mostly to cross and become connected with the left side of the brain. This crossing occurs principally in the upper part of the cord, and in the medulla oblongata. The general course of these fibers is shown in the diagram (Fig. 84), in which the dotted line *M* represents the course of the motor fibers, while the unbroken line *S*, that of the sensory fibers. The circle represents the brain, and the cylinder the spinal cord.

The sensory fibers enter the cord by the posterior roots, and those that come in on the right side, for the most part,

enter the gray matter and cross to the opposite side of the cord immediately, and ascend to the left side of the brain.

This statement, while it holds good for the greater number of the fibers of the cord, is not complete in the details of the paths of the fibers. The question of their complete distribution is too intricate to be discussed here.

Paralysis.—From this crossing over of the fibers from one side of the body to the half of the brain on the opposite side we have the explanation why an injury to the left side of the brain may produce paralysis—that is, loss of motion and sensation—on the right side of the body, or *vice versa.*

The crossing over of the motor fibers above, and of the sensory fibers below, accounts for the fact that an injury to the right half of the cord may produce loss of *motion* of the *same* side and loss of *sensation* on the *opposite* side.

Reflex Centers of the Medulla.—The *medulla oblongata,* like the spinal cord, has a number of reflex centers in it. The main ones which have been traced to it are: A center that *winks the eyes;* one that *sneezes;* one that *coughs,* the one that controls the *secretion of the saliva;* the *swallowing center;* a center that produces the *act of vomiting;* one that *dilates the pupil* of the eye; and one that *masticates the food.* It also contains the group of cells that carries on the acts of breathing, and from this fact called the *respiratory center.*

Respiratory Center as an Automatic Center.—While this center, or part of it, may be made to act as a reflex center—that is, acts of breathing may be made to take place by stimuli coming in from sensory nerves—yet it differs from purely reflex centers by having the power of periodically discharging impulses without receiving any nervous impulses from without to stimulate it to action. (See chapter on Respiration.) Such a center is known as an *automatic center.*

Cause of the Action of the Respiratory Center.—The cause of the discharge of the stimuli in this case is probably in the condition of the cells in the center caused by the state

of the blood passing through it. As the blood becomes deficient in oxygen it causes the center to discharge an impulse which causes the respiratory act. This improves the condition of the blood, and the act ceases until the blood again loses its oxygen, when immediately another discharge takes place, and so on, keeping the respiration going. Thus a sample of the blood which the respiratory apparatus is working on to purify is sent through the center and made to regulate the rate and vigor of the machine.

This is certainly as beautiful a contrivance as that of making some of the steam pass through a part of the machinery of an engine, to regulate the motion of the machinery. This is done at the part called the "governor."

Importance of the Medulla.—Considering the number and the importance of the centers located in the medulla, the serious effect of even a slight injury to it may be understood. A small wound in certain parts would produce instant death by injury to the respiratory center.

"Breaking the neck" results often in instant death by injury to the lower part of the medulla. Cattle are frequently slaughtered quickly and without pain by thrusting a sharp instrument so as to pass between the skull and the atlas, thus piercing the vital point.

Economy of Reflex and Automatic Centers.—Reflex centers also exist in the brain, and many of the sympathetic ganglia have reflex functions. Only a little thought is necessary to perceive that the reflex and automatic centers are great labor-saving contrivances.

The many complex actions involved in mastication, in swallowing, in digesting, in respiration, in circulation of the blood, in the action of the glands, and in most of the actions of walking, running, sitting, standing, balancing, in movements of the arms, and indeed the great majority of the actions which the body must perform in a single day, could not possibly be done by our own conscious attention and effort.

We are wholly ignorant of how to manage the greater number of these actions. In respect to the remainder, they are so very complex that we could not find the time to give attention to their working were we able to control each individual muscle, which is not the case. Instead of having so much fatal responsibility thrust upon us, we find in our bodies a large number of nerve groups which are parts of self-regulating mechanisms, which will carry on these operations without any thought or attention on our part, even while we are unconscious of our acts.

The touch and sight of the ground will guide and regulate our steps. Touch and sight will control the motions of our hands in many forms of work. The contact of the food against the walls of the stomach will of itself bring on the proper motions and secretion of the juices and other conditions necessary to its digestion.

In a thousand other ways the stimuli that come pouring into the nerve centers from the other parts of the body and from the outside world are made to work these mechanisms perfectly, so that the body can maintain itself a considerable length of time by these contrivances without the help of our consciousness.

Functions of the Cerebellum.—The large size of the cerebellum, and the fact that it is by its numerous fibers connected directly with the spinal cord, medulla, and cerebrum, would lead us to suppose that it played an important part in the economy of the nervous system. However, it has not received that amount of study by physiologists that has been bestowed upon other parts of the nervous system. As the result of this, with other difficulties in the way, we are left without any great amount of definite knowledge in regard to its functions.

It does not seem to be greatly, if at all, involved in psychical operations, as neither the will, sensibilities, nor the intellect seems to be affected by any injury to it.

Such injuries, however, always cause some loss of power to coördinate voluntary movements, but even this loss may be only temporary, unless the injuries are very great. For example, an animal with the cerebellum injured, while still able to move its limbs, and seemingly as intelligent as ever, loses its power to make the muscles work together well enough to walk straight, to fly, or even to stand. But it may finally recover this power without a restoration of the parts of the cerebellum that were injured.

It would seem from all the experiments and observations made on the subject that, at least, it may be said to be a center for the *more perfect coördination of the movements of the body*, especially of the more delicate ones, such as balancing the body and those fine adjustments by which the wonderful movements of the hand and arm can be accomplished.

Functions of the Mid-brain.—The functions of the mid-brain, the *corpora quadrigemina*, in man are not known, but disease of this region affects vision and the power of coördinating movements. So this region seems to be connected with those operations.

Psychic Centers.—The nerve centers thus far described are: (1) Reflex centers; (2) automatic centers. There remains one other class of centers—(3) *psychic* centers. The psychic centers are distinguished from the other classes by the fact that they are connected with the mental operations—that is, those of the *will*, of the *sensibilities*, and of the *intellect.*

The greatest interest is attached to this study of the parts of the cerebrum, for physiologists feel pretty sure that somewhere among its groups of countless cells and its intricate labyrinth of fibers are to be found those cells whose wonderful office it is to be concerned with the processes of thought.

The exact location of these favored groups has not yet been agreed upon. Many opinions have been more or less confidently advanced in regard to their location.

The "seat of the soul" has been fixed at several different

points in the body, and some of these outside of the nervous system itself. But in many cases the selection of any particular group of cells as the one connected with *psychic* operations exclusively has been a mere matter of opinion, based on fancy rather than the result of any scientific observation and experiment.

To-day, while there is pretty general agreement that the psychic centers lie somewhere in the cerebrum, yet, notwithstanding the immense amount of observation and experiment made in the investigation of this subject, physiological science does not assert with confidence the exact boundaries of the psychic centers.

Evidence that the Psychic Centers are in the Cerebrum.—It is possible to remove the cerebrum from many of the lower animals without producing immediate death.

An animal with the cerebrum removed, but with the other parts of the nervous system uninjured, may be able to perform a great many complex movements; it may carry on respiration, circulation, and digestion perfectly enough to keep itself alive for a considerable length of time. But in this condition a careful study of all its actions would show that they are all either reflex or automatic.

All power of *voluntary motion* is lost. The animal manifests not the slightest evidence of any emotion, such as fear. It shows no longer the evidence of intelligence which its former actions manifested. In every way it is simply a machine.

Compared with an uninjured animal, there is the immense difference which exists between the action of a blind machine, and the action of one controlled by a will influenced by emotions and at least a degree of intelligence.

In man, whenever the cerebral hemispheres are injured by accidental wounds or by disease, the mental operations are disturbed.

Evidence from these two sources has been so multiplied

that there is no doubt that the psychic centers are within the cerebrum.

Relation of the Nerve Centers to Each Other.—In the diagram shown in Fig. 85, the relation of the principal centers to each other and to the outer organs with which they are connected is shown.

The upper folded part represents the gray matter of the *convolutions*. The two elliptical figures represent the two largest of the ganglia described in the preceding chapter. The one on the left is the *corpus striatum;* the one to the right, the *optic thalamus*. The portion immediately below these is the *medulla*. The part below the medulla is part of the *spinal cord*. The *cerebellum* is shown on the right.

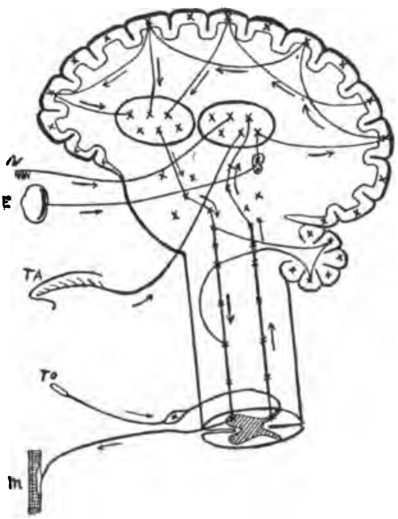


Fig. 85.

Diagram showing the Relation of the Cerebro-spinal Nerve Centers to each other and Their Connection with Sense and Motor Cells.

The explanation is given in the text. Compare also Figs. 45 and 61.

The lines with the arrows are to represent the nerve fibers, and the direction of nerve impulses along them. A muscle fiber is represented by *M;* and *N*, *E*, *Ta*, and *To*, represent the sense-organ cells of smell, sight, taste, and touch. For simplicity, the nerve centers of the medulla with the nerves are omitted, but the diagrams of the nervous control of the circulatory organs and of respiration may be compared with this (Figs. 61 and 45).

Let us consider for a moment, with the aid of Fig. 85, the operation of the nervous system. If the touch cell is pressed upon, impulses will travel along its nerve to the gray matter of the spinal cord. This will immediately send impulses out to the muscle cell (*M*), and, as the result, a motion is produced. This is a reflex action. But as the gray matter of the spinal cord is also connected with the optic thalamus, and this with the convolutions, impulses may arrive at the last point and give rise to the sensation of pain.

This point of the gray matter of the cerebrum also has its cells connected with the cells of the convolutions. By means of these connections the various operations involved in thinking a matter over take place, and the conclusion as to what is to be done in the case is reached.

When the judgment is formed, the will sends a stimulus to the corpus striatum, from which it is forwarded to the spinal cord. This having received its orders from the higher center, proceeds to execute them through stimuli to muscles.

Now, the stimuli may come in from *E*, or *Ta*, or possibly from all the incoming fibers, and from many other sources as well. In fact, stimuli are streaming into these centers all the time.

The diagram shows very few elements. In the actual nervous system these elements are many thousands of times multiplied. Constantly over these intricate paths the nervous impulses are swiftly darting to and fro.

Many coming in and passing out produce various motions, but no consciousness; while others, ascending to the higher centers, give rise in a mysterious way to the formation of ideas on the one hand; or others, on the other hand, in a no less mysterious way, receive impulses from the will, which they finally convert into motions.

The Effects of Alcohol on the Nervous System.— Soon after liquids containing alcohol are taken into the

stomach the alcohol is absorbed into the blood vessels and distributed all over the body. It exerts an immediate effect on the central nervous system. The brain is especially affected. Even small doses will disturb the normal functions of the brain. This is shown in the false judgments one soon begins to make. The mildest examples of these are such as feelings of warmth or coolness when the subject is really no warmer or colder, or exaggerated views of the enjoyment or suffering that one may be in for the moment. Indeed it is mostly for the more or less exhilarating feelings that follow its immediate use that an alcoholic drink is taken. But such feelings are only the result of a deception in regard to the real condition, which is produced by a certain degree of disturbance of the normal action of the central nervous system. It is obvious that if for any considerable time we were deceived by our nervous system in regard to our actual state, and our relations to things around us, we must suffer from inability to adapt ourselves to these conditions. It would seem reasonable to suppose that an intelligent being would be anxious to have the highest functions of his body act as normally as possible.

Larger doses of alcohol will increase this disturbance. The result is a greater degree of misinterpretation of the sensations, a derangement of the judgment, a loss of power for intellectual acts, a loss of voluntary control over the muscles, and loss of power of coördination. In short, the powers of the intellect, the sensibilities, and the will are to a greater or less degree disturbed, or may be completely lost for the time. Of course, if this last stage should be continued for a length of time by repeated doses, only death could result. These last stages of excessive use of alcohol are well known to so profoundly disturb the functions of the brain as to result in frightful diseases, such as *delirium tremens* and insanity; and they are the direct cause of some of the most terrible crimes committed by human beings.

Even the moderate use of alcoholic drinks, if habitual, will in time, in greater or less degree, produce structural changes in the brain. In some persons the results of such change may not appear on the surface, while in others they become most marked. As far as understood, they consist of greater development of other elements to the detriment of the nerve cells, and probably result from the general disturbance of the nutritive processes of the body, the evil effects of which the brain shares with the kidneys, liver, heart, and other organs.

There is no doubt that alcohol acts on the various organs of the body largely through its influence on the nervous system. As many of these effects are shown on the body as a whole, it has been thought best to give a general discussion in a single chapter bringing together these facts and their significance. The student is referred to Chapter XXII., pp. 288–294.

Directions for Practical Work.

Reflex Action.—If a hot object is touched with the tip of the finger, the hand will be found to move before the pain is felt. Of course, as the intervals of time are very short, it will require close observation to note this. What moves the hand?

Study carefully the motions of the body in attempting to walk a narrow path, like a railroad track, and distinguish the voluntary from the reflex. Keep some one under observation for an hour, and of all the motions that the person makes determine which you think are voluntary, and which reflex. Analyze a number of common movements to see if any of them are due to reflex action.

If a frog, toad, or turtle be decapitated, many very complex motions may be obtained from it by stimulating different parts of its body. These motions may be seen to occur only on the application of some stimulus.

Parts of the bodies of animals lower than these, which still retain a portion of their nervous cord, will show reflex actions.

The hydra, studied in this connection as an animal which produces motions without a nervous system, is instructive.

Review Questions.

1. What are the general functions of the nervous system?
2. Illustrate this.
3. What is coördination in the body?
4. How does the example given illustrate coördination?
5. What is the case with one-celled animals?
6. How is coördination accomplished in the hydra?
7. How do animals differ in this regard as we ascend the scale?
8. In what ways may the body be compared to a community?
9. In such a community, to what may the nervous system be compared?
10. What is the function of a nerve fiber?
11. What are the sources of nervous impulses?
12. Upon what does the conduction of a nerve fiber depend?
13. What are the properties of a nerve cell?
14. On what does this property depend?
15. What substances outside of the body possess properties similar in this respect?
16. What are they used for?
17. What are the functions of the nerve cells?
18. Reproduce the diagram of the simple nervous apparatus and explain its action.
19. What mechanical advantages would be secured by such arrangements?
20. What is said of the nature of a nervous impulse?
21. What evidence is there against its being an electrical current?
22. What comparisons can you make to the nervous mechanisms from among human inventions?
23. Reproduce Fig. 83, and show what might result from such a nervous apparatus.

24. How are these elements of a nerve cell and nerve fiber arranged in the nervous system?

25. What of the complexity of the system?

26. What of the plan in this complexity?

27. What stimuli affect a nerve, and which one is made use of in the body?

28. What is the velocity of a nervous impulse? What velocity does a railroad train reach? What is the velocity of sound? What of light?

29. How does the velocity of a nervous impulse compare with these?

30. What are the conditions which affect the activity of the nervous tissues?

31. How may this be shown?

32. What is a reflex action?

33. Describe the reflex actions of the human body?

34. What is a reflex center?

35. What part of the nervous system may act as reflex centers?

36. How has this been proved?

37. What of the spinal cord as a conductor of impulses?

38. Describe the course of the fibers in the spinal cord. Illustrate with a diagram.

39. How does this explain certain forms of paralysis?

40. What are some of the reflex centers of the medulla?

41. What is an automatic center?

42. What is the cause of the action of the respiratory center?

43. What of the importance of the medulla?

44. Show how reflex and automatic centers are labor-saving contrivances.

45. Give ten illustrations of this fact.

46. What are thought to be the functions of the cerebel lum?

47. On what evidence does this opinion rest?

48. What is said of the functions of the mid-brain?

49. What is the classification of the nerve centers?

50. What are the psychic centers?

51. What is said of their location?

52. Give the evidence for the view that these centers are located in the cerebrum.

53. Reproduce the diagram in Fig. 85, and illustrate the general actions of the nervous system by this means.

CHAPTER XIX.

GENERAL SENSATIONS—SENSATIONS OF TOUCH, TASTE, AND SMELL.

Sensation.—In the study of the nervous system it has been shown that there are two kinds of nerves: (1) Those that conduct nervous impulses out *from* the nerve centers—the *efferent;* and (2) those that conduct nervous impulses *to* the nerve centers—the *afferent* (or sensory, as they are also called). In very many cases it has been shown that the sensory impulses, coming into the centers, serve to start an outgoing impulse without producing a consciousness of these impulses. This is seen in such reflex actions as are made use of in the circulatory, the respiratory, and other mechanisms.

When, however, the incoming impulses proceed to certain centers—the psychic centers—in the brain, and we are made conscious of their presence, sensations are produced. We then recognize a state of feeling in which we more or less clearly perceive something, such as the more definite things, as sound or light, or the less definite ones, as pain or hunger.

The sensory nerves, which are the paths of these impulses, come from every part of the body. They are the source of all our knowledge of the world outside of ourselves; of our knowledge of the thoughts and actions of others, and of the state of our own bodies.

Most of the sensory nerves have their outer terminations in the tissues in a manner not yet discovered. Certain of the sensory nerves are known to end in special forms of cells; for example, those of the retina in the eye. These

are so constructed as to be aroused into activity by some special stimulus, as light, in the case of the retina.

The organs furnished with these special cells are called special-sense organs, and the sensations we obtain through their means are the special senses, which are at least six, viz.: the *sight*, *sound*, *taste*, *smell*, *touch*, and *temperature* senses.

General Sensations.—The other sensations, which depend on a variety of stimuli coming from many parts of the body, but not due, as far as we know, to any definite organs at the outer extremities of the nerves, are called the *general sensations*. Examples of these are hunger, thirst, nausea, and pain in its many forms; feelings of comfort or discomfort, of horror, and others hard to describe on account of their indefiniteness.

The general sensations are of very great importance. Hunger and thirst, with the feeling of satisfaction when enough food or drink has been taken, have been referred to as indispensable guides in regulating the supply of food and drink. They drive us to the greatest exertion to secure the proper supply, if such exertion becomes necessary.

These feelings are the result of the action of a portion of the nervous system which, while it has not been definitely isolated from the rest, still no doubt exists as a definite mechanism.

Ideas Gained from the Sensations.—The ideas which we obtain of external objects are in the majority of cases, if not in all, the result of complex processes. When an organ of special sense is stimulated by an external object, the idea resulting is not the simple product of that single sensation, and is in no sense of the term similar to the stimulation. The idea is the interpretation of the effect of the stimulus, which interpretation is made in the light of many experiences of the past, and is so complex that any analysis of its elements must necessarily be only approximate.

Pain.—This sensation is graded through so many degrees,

from that of great intensity to that of a mere feeling of discomfort or annoyance, that it would be hard to define the term. Any sensory-nerve fiber seems to possess the power of giving rise to the feeling of pain. Even the same stimulus, while it is producing a pleasurable sensation, may, by a slight change in its intensity, or in the manner of its application, give rise to pain.

By means of the sensations of pain, the body is stimulated to attempt to remove the causes which would result in its injury. Pain drives us to remove cinders from the eye, splinters from the fingers; to avoid water that is too hot, light that is of too great intensity, and a thousand injurious conditions, without waiting for us to learn just why they are injurious, or leaving to our negligent habits attention to these injuries.

When we are called to consider the sufferings of those who have in battle or by severe accidents received serious wounds, it is a relief to know that the intensity of pain is not proportional to the severity of the wound.

Livingston in describing his sensations when a lion sprang upon him and crushed his arm, states that he was almost without pain at the time. Soldiers who have received the most severe wounds describe sensations which seem incredible to us who judge from the pain of our own slight injuries.

Special Sensation.—The essential parts of each special sense apparatus are: (1) Cells capable of being stimulated by the special form of energy that acts on that sense organ; (2) a nerve to conduct the impulses thus produced; (3) the nerve centers to receive the impulses and give rise to the sensation. The right half of the diagram in Fig. 82 would represent the essential parts of an organ of special sense.

The Sense of Touch.—This sensation is aroused by pressure on some part of the skin, of the mucous lining of the mouth, or of the beginning of the nasal passages.

It has been discovered that the sensory nerves in the skin

end in several differently and peculiarly formed groups of cells. Some or all of these, no doubt, contain the sense-organ cells of touch.

These elements of the organ of touch are more numerous in the tips of the fingers, the palms of the hands, in the lips, tongue, and in the soles of the feet than elsewhere. They are, however, scattered throughout the skin. The pressure on the epidermis is communicated to these elements, which are special contrivances to convert the pressure into nervous stimuli.

Location of the Point touched.—The part of the skin touched can be determined with a greater or less degree of accuracy. From some portions of the skin we gain much more definite knowledge than from others. Thus, with the eyes closed, we could not tell the definite shape of an object by having it brought in contact with the skin of the forehead, of the back of the hand, or, indeed, with most parts of the body.

But if the object is examined with the tips of the fingers, or lips, or tip of the tongue, or by the toes, its shape can be made out. A pair of compasses may be used to determine the least distance at which two points on different parts of the skin can be distinguished as distinct locations. The distance will be found to vary all the way from one sixteenth of an inch at the tip of the tongue to three inches on the back of the neck. Thus it is seen, while every part of the skin will report the presence of objects, only certain parts will furnish very definite knowledge of them.

Comparison of the Organ of Touch with other Sense Organs.—The other organs of the special senses might well be considered as more highly developed and more specialized touch organs. Just as in the skin some points are specialized in such a manner as to give knowledge of form and temperature, so another part—that in the mouth—is specialized to give knowledge of certain qualities of substances in

solution, and a portion in the nose to give knowledge of gases. In the same way we have the retina of the eye and the auditory cells in the ear as definite areas to determine, the one light, the other sound.

The Sense of Temperature.—The skin also gives us knowledge of the differences of temperature. Some of the sensory nerves of the skin end in organs whose special function is to originate nervous impulses in the nerve fibers with every change of temperature. Just which of the several kinds of sense-organ cells in the skin have this for their function is not known. But it has been proved that the temperature sense-organ cells and nerve fibers are different from those of touch in many portions of the skin.

The Sense of Smell.—The organ of smell is the mucous lining of the higher parts of the nasal passages. It covers over two projections of the ethmoid bone, known as the upper and middle turbinated bones. It also extends over the upper region of the septum, the partition between the nostrils.

The lower turbinated bones have no fibers of the olfactory nerves distributed to them. Their mucous membrane bears ciliated cells. It contains nerves from the fifth pair, which render it very sensitive to the contact of foreign bodies.

The Olfactory Cells.—The special cells which are affected by odors are slender cells wedged in among the column-shaped cells of the epithelium of the mucous membrane. Their outer extremities come to the very surface. The surface of the mucous membrane is constantly moist with mucus.

The ends of the olfactory cells are connected with the fibers of the olfactory nerve, which is shown in Fig. 86. These nerves are shown also in Figs. 75 and 76. They are the first part of the cranial nerves. They branch while still within the skull into very many divisions, which come through

little perforations in a portion of the ethmoid bone. The brush of nerve fibers is shown in the figure below. The lower nerve shown in the same figure on the inferior turbinated bone is a branch of the fifth cranial nerve.

Fig. 86.

SECTION THROUGH THE BONES OF THE FACE, TO SHOW THE DISTRIBUTION OF THE OLFACTORY NERVE.

The Sensations of Smell.—The sensations of smell must be produced by the direct contact of the odors with the sense-organ cells. We know very little of the nature of odors, or of their manner of acting on the olfactory nerve cells.

In ordinary breathing through the nose, enough air passes above the inferior turbinated bones to reach the olfactory surfaces. This is sufficient for detecting any moderately strong odor in the atmosphere, but when we wish to examine the air carefully for odors, we sniff it with considerable force. This action throws the air in greater quantities directly upon the olfactory membrane. By this means astonishingly small amounts of odorous gases can be detected in the atmosphere.

By the sense of smell we may distinguish a great number of different substances, but we are totally ignorant of how these differences are known.

The Function of the Sense of Smell.—The function of the sense of smell is mainly to detect the presence of deleterious gases in the air in breathing, and to aid in selecting food. In the lower animals it serves other functions as well

Certain of them find their food almost wholly under its direction; others depend on it largely to warn them against enemies.

Many animals make use of the sense of smell very largely in becoming acquainted with the things around them, and in finding their way from place to place. The sense of smell in such animals as the dog, cat, and horse is more highly developed than in man. Such animals in a wild state could not long survive the loss of this sense. In man its function is not so important.

The Sense of Taste.—The parts of the mouth which seem to possess the power of tasting are the tip, root, and edges of the tongue, and probably the lower part of the soft palate.

The sense-organ cells of taste are found in little (microscopic) bulb-shaped groups, called *taste bulbs.* The central cells of the bulb end externally at the surface, while the inner ends are connected with fibers of the nerve of taste (the glossopharyngeal and branches of the trigeminal).

To produce the sensation of taste, the substance must be in solution. In consequence, the saliva greatly aids the sense of taste.

The Varieties of Sensation of Taste.—We know very little of the manner by which different kinds of tastes are produced. We recognize four kinds: sweet, bitter, acid, and saline. The flavors of foods and drinks are really smelled, not tasted, as is commonly thought. This can be proved easily by putting strongly flavored substances, such as a piece of onion or some food flavored with vanilla, into the mouth while the nostrils are securely closed, when it will be found that these substances have lost their characteristic taste. The different flavors of meats and fruits are wholly a matter of smell.

The Function of Taste is mainly to aid in the selection of food. It seems to be, together with smell, very generally possessed by the lower animals; at least, they all show the power to select food.

The Muscular Sense, or Sense of Weight.—We can, independent of any other sense organ, determine the approximate weight of a body by lifting it.

This is determined by sensations which come either from nerves in the muscles themselves, or in some manner by the amount of exertion which the motor centers must put forth in the action performed. This is sometimes given as a special sense. By its means we certainly gain as definite ideas as by some of the special senses.

This sense is constantly made use of to guide the effort to be made in each action. If it were not for this sense, what was meant for a gentle motion might turn out to be a rough one; nothing could be handled in the proper manner.

Directions for Practical Work.

With a pair of compasses, whose sharp points are guarded with little pieces of cork, test the skin at different points to see what is the least distance at which two points can be distinguished as two.

Cross the first and second fingers, and while the eyes are closed place a pencil between the two ends of the crossed fingers, and the pencil will appear to be two objects. Explain.

By means of a rod of metal heated by dipping it into a vessel of hot water, determine those portions of the surface of the skin most sensitive to heat.

If, while the tongue is dry, dry quinine or sugar be placed on its surface, it will produce no taste. Why?

By means of a small brush, test different parts of the tongue with solutions of bitter, sweet, sour, and saline substances, to determine where each is best distinguished. The amount used must be small and the mouth rinsed after each test is made.

Close the nose and put a bit of onion in the mouth. Its "onion taste" can not be distinguished until the nose is opened. Other substances with flavors may be tested in the same way to show they are smelled and not tasted.

Review Questions.

1. In what case may impulses from an afferent nerve not produce consciousness?

2. When do they produce sensations?

3. Where are the sensory nerves?

4. How do they terminate?

5. What are the special senses?

6. What are general sensations?

7. What can be said of their importance?

8. What is said of the ideas gained from sensations?

9. How is pain produced?

10. What are the uses of pain?

11. What are the essential parts of the sense apparatus? Illustrate by diagram.

12. How is the sense of touch aroused?

13. How do sensory nerves end in the skin?

14. Where are the elements of the organ of touch most numerous?

15. What is said of the definite location of the point of the skin touched?

16. What parts give most definite knowledge of the shape of an object?

17. How may the sense of touch be compared with other senses?

18. What is the sense of temperature?

19. Where are its nerves and sense-organ cells?

20. What and where is the olfactory region?

21. What is said of the olfactory cells?

22. Where is the olfactory nerve, and how is it distributed?

23. What nerve is distributed on the inferior turbinated bones?

24. To what is it sensitive?

25. How are sensations of smell produced?

26. What is the means of getting the odors in greater abundance to the olfactory surface?

27. What are the functions of the sense of smell in man? In the lower animals?
28. What parts of the mouth are sensitive to taste?
29. How are the sense-organ cells of taste arranged?
30. What conditions are necessary to taste?
31. What are the nerves of taste?
32. What are the varieties of taste sensations?
33. What are flavors?
34. What are the functions of taste?
35. What is said of the muscular sense?
36. What are its functions?

CHAPTER XX.

THE EYE AND THE SENSATION OF SIGHT.

The Sensation of Sight.—The essential parts of the apparatus for sight are: the retina, the optic nerve, and the nerve centers with which its fibers are connected. The visual apparatus in many of the lower forms of animals consists of no more than these three essentials. In such a case the cells which are affected by the light are placed among the epidermal cells of the skin. They are really another form of epidermal cells. The nerve fibers end at their lower extremity, and connect them with a nerve center. Such an eye, as in the star-fish and in many other animals, certainly can not see much. It can detect the presence or absence of light, and perhaps that is all it can do.

Between such a simple eye as that and the very complex visual apparatus of man there are in the animal world examples of every degree of complexity. But in all there are cells affected by light (retinal cells), a nerve, and a nerve center. This explains further what is meant by the three parts given as being essential. All the parts of the human eye, except the retina and the optic nerve, must be considered as accessory parts, whose functions are to bring the light in certain ways to the retina.

The Globe of the Eye.—The globe of the eye (Fig. 87) is formed on the plan of a photographic camera, in which the sensitized photographic plate is replaced by the *retina* (*a*, *b*, *b*). The firm walls of this camera are made up of the *cornea* (1), the clear transparent membrane in the center of the front of the eye, and the *sclerotic coat* (2), the tough

white portion seen just back of the edge of the cornea. It extends around the whole of the back of the eye, except where the optic nerve enters the globe. At this place it is continued as the sheath of the optic nerve (2′).

The *sclerotic coat* is immediately lined by a dark-colored coat, the *choroid* (3), which is crowded full of blood vessels, whose blood furnishes the main supply of the nutrition of the

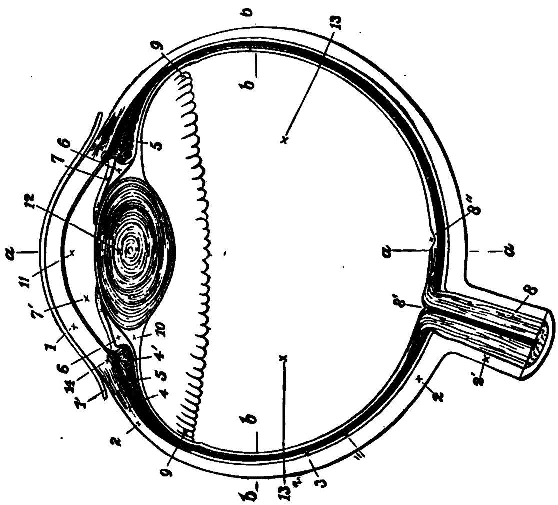


Fig. 87.

SECTION OF THE EYE.
The explanation is given in the text.

eye. The choroid coat is continued forward into the circular curtain just back of the cornea, called the *iris* (7).

The iris is plainly seen as the colored part in the front portion of the eye. The dark round spot in its center is the *pupil*, and is an opening in the curtain. It is black simply because it is the open window of a little room whose walls are dark.

The retina lies next to the choroid. Its structure will be

discussed presently, but it may be stated here that its special tissue is supported by a peculiar connective tissue, whose elements are continued forward and join the capsule of the *crystalline lens* (12) and hold that organ in place. Thus it is seen that the walls of the camera box consist of three layers.

The walls are held out in a globe shape, mainly by the *vitreous humor* (13), which fills all the space between the crystalline lens and the retina. It is a transparent substance having the appearance of jelly.

The *aqueous humor* consists of a few drops of a liquid like water. It fills the space between the lens and the cornea and serves to hold the latter out in a convex shape. It is transparent (11).

The Lenses of the Eye.—Like the camera, the eye carries in its front part lenses whose action on the light is to make on the back part of the eye distinct images of the objects before it. The front lens is formed by the cornea with the aqueous humor behind it. The next is the crystalline lens.

The Cornea.—This is the front transparent portion of the globe of the eye. By examining the eye of one's companion from the side, it is seen to project slightly beyond the general curvature of the ball of the eye. It is simply a continuation of the sclerotic coat made transparent.

The Crystalline Lens.—This is usually known as simply the *lens*. It is a beautifully transparent solid body, about one third of an inch in diameter and about one fourth of an inch in thickness. It is doubly convex, being more convex behind.

It is surrounded by a thin membrane, the capsule, whose edges extend and become the means of holding the lens in place. The lens is elastic. The inner margin of the iris rests on its front surface.

The Ciliary Muscle.—Just beyond the outer margin of

the iris and at the front portion of the choroid coat (4 and 4′ in Fig. 87) is the *ciliary muscle.* This is a circular band of involuntary muscle fibers. The fibers are longitudinal, running from the cornea backwards, and circular. The figure 4′ points to the circular portion.

The Formation of an Image in the Eye.—If a convex lens is held between a window and a sheet of paper, and the distance between the lens and the paper properly adjusted, it is found that an inverted image of the window is formed on the paper. In the camera, the image at the back is formed by the lenses in front. For the explanation, the reader is referred to works on Physics. The cornea and crystalline lens act in the same way to form an image at the back of the eye.

The image in the eye is formed at the surface where the retina lies against the choroid coat, all the parts before this surface being transparent, and consequently unable to reflect an image. The formation of a distinct image is necessary for distinct vision.

Accommodation of the Eye to the Different Distances of Objects.—In attempting by means of a hand lens to form images of a lamp flame on a sheet of paper used for a screen, it would soon be found that when the lamp is at a greater distance from the screen the lens must be carried farther toward the screen, and *vice versa.*

The photographer accommodates his camera to the different distances of objects to be photographed by either changing the position of the lens or the back of the camera. His "focusing" consists in this. He makes the distance between the lens and the back of the camera greater for nearer objects and less for distant ones.

If, when the camera is arranged so as to give a good image of an object on its ground-glass plate, it is brought nearer to or carried farther from the object, the image immediately becomes indistinct.

It is so with the eye. If one look at an object across the room, say a word written on the blackboard, and while seeing that clearly will bring his finger close in front of the eye, he will find that the finger is very indistinct; the detail of lines on it can not be seen.

If now he looks at the lines on the finger, the word on the blackboard is indistinct.

The eye evidently has means of accommodating itself to distant objects.

Since the walls of the camera of the eye are immovable, it finds its means of accommodation in another way. This is accomplished by the convexity of the crystalline lens. The more convex the lens the nearer to it must the screen be moved if the distance of the object remains the same. By using lenses of different degrees of convexity, the distance between the lens and screen could be kept the same for objects of different distances. In such a case the nearer the object the more convex the lens must be.

In the eye the crystalline lens is made to change its convexity, being made more convex for nearer objects, and less convex for more distant ones.

How the Crystalline Lens is Changed in Form.—That the lens does change its form by the anterior surface becoming more or less convex has been clearly proved, but how this is accomplished is not so easily demonstrated. But the explanation is thought to be as follows : The lens is elastic, and when the eye is at rest the capsule (consult the figure) is put on a stretch by its connections. This tension flattens the front part of the lens slightly. This, in the normal eye, is just the focusing necessary to see distinctly distant objects—that is, objects twenty feet or more away.

When the eye is fixed upon a nearer object, the circular fibers of the ciliary muscle (4′) are contracted, and since this muscle is firmly attached to the membrane which suspends

the lens (consult the figure), the contraction lessens the tension on the capsule of the lens. The elasticity of the lens causes its front surface thus released to spring out in a more convex outline.

By carefully studying Fig. 87, which is a very accurate one, in connection with the above description, this action may be clearly understood.

Perhaps the most important function of the crystalline lens is that of accommodation.

The cornea, without the aid of the crystalline lens, is able to form a distinct image; but having no motion, it is fixed for one distance.

Action of the Iris.—The functions of the iris are to cut out such rays of light as would confuse the image and make it indistinct, and to reduce the amount of light when it is too bright.

Most optical instruments are furnished with what are known as diaphragms, which serve for them the same purpose. They are in constant use in microscopes and photographic cameras.

The opening in the iris, the *pupil*, is made small by the contraction of a circular muscle in its inner margin. It is enlarged by the contraction of the radial fibers.

Nervous Control of the Iris and Ciliary Muscle.—The iris and ciliary muscle are connected by nerves with nerve centers, which are also connected by nerve fibers to the retina. The whole constitutes a self-regulating apparatus, the light on the retina regulating the motions of these muscles to the needs of the occasion.

The Retina.—The parts of the eye described in the foregoing sections are to be regarded as accessory parts of the organ of vision, the essential parts being, as we have stated, the retina, the optic nerve, and the nerve centers in the brain.

The retina is a very complex structure. It lies at the back

of the eye between the choroid coat and vitreous humor, extending forward to the scalloped line shown in Fig. 87 at 9, called the *ora serrata*.

It is about one fiftieth of an inch in thickness in the central part, thinning out to one two-hundredth of an inch along the front margin. As thin as it is, as many as ten layers are recognized in it by histologists. It consists of a nervous part, shown in Fig. 88, *A*, and a skeleton of a peculiar kind of connective tissue, which is shown separated from it in *B* in the same figure.

The layer toward the vitreous humor consists of nerve fibers (Fig. 88, next to the letter *A*) that come from the optic nerve, which pierces the other coats of the eyeball, as seen in Fig. 87. These nerve fibers pass to the other layers of the retina, being connected through the different kinds of cells and fibers, well shown in Fig. 88, until they reach the layer of the rods and cones, which are turned toward the choroid coat. There is a layer of pigmentary

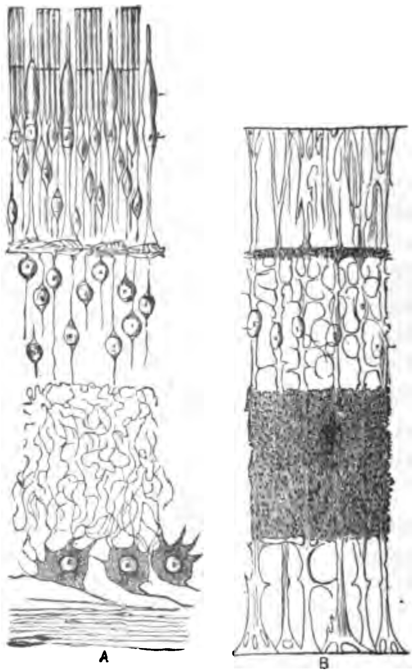


Fig. 88.

RETINA.

A, nervous elements; *B*, connective-tissue part separated from *A*. The upper part is the part turned toward the choroid coat.

cells belonging to the retina, not shown in the figure, which is at the free ends of the rods and cones.

The Rods and Cones.—These are peculiarly shaped cells, and are considered to be the sense-organ cells of the eye in which the nerve fibers of the optic nerve terminate.

These are the cells which are capable of being so affected by light as to give rise to nervous impulses, which, conducted by the optic nerve to the centers in the bra.. produce the sensation of sight.

Action of Light on the Rods and Cones.—. 'st what the action of the light is on the rods and cones is not definitely known. While it is out of place to discuss the theories on this subject here, yet it may be said that it has been thought by many physiologists that reasons exist for believing that these impulses are originated by chemical changes produced by the light in substances either around or in the free ends of the rods and cones.

The Region of Distinct Vision.—Not all parts of the retina are equally sensitive to the same kinds of stimuli. It is only with a very small portion of the retina that we can see definite outlines. This part is in nearly the central point in the back of the eye. In the figure, the point is at 8″, *a* being the central point. The exact location may vary for different eyes. This is called the *yellow spot.*

To show that this is true, fix one eye on a word on a page of print, and note that if the eye is not allowed to move, words a very short distance from this one can not be made out. The image of that word is on the yellow spot, while those of the others are outside of it. It is only by moving the eyes rapidly over the lines that the words are seen in sentences.

The Blind Spot.—At the place where the optic nerve enters the eye, light produces no sensation. This is shown by holding this book so that the letters below—

O **X**

may be in a horizontal line at about a foot in front of the face. Close the left eye and fix the right on *O*. Both letters can be seen, but if the book be moved slowly about, revolving it on *O*, at certain positions the *X* will entirely disappear. The image of the *O* is on the yellow spot, and whenever the *X* falls on the blind spot it disappears.

Motions are well perceived by all parts of the retina (except at the blind spot).

Different colors are more distinctly seen by some parts of the retina than by others.

The Inversion of the Image.—The image of the object seen is inverted in the eye. This fact has been made a puzzle of, but it need present no difficulty when it is remembered that the sensation of sight is not made at the retina, but is the interpretation of the state of the retina through its nervous connections.

Our sensations are nothing like the things that produce them. By experience we have learned that those things to which we must lift the eyes or raise the hands affect us in one way, while those to which we must lower the hand affect us differently, and from these facts we learn up and down. We would never have suspected that any image is formed in the retina at all without having examined the structure of the eye.

Blood Vessels in the Retina.—The main supply of blood to the retina is probably through the choroid coat. Still it has an artery of its own, which comes into it through the center of the optic nerve (seen in Fig. 87), and is distributed through the fibrous layer of the retina (the layer next to the vitreous humor).

An interesting experiment which will show these blood vessels, and at the same time prove that it is not this coat of the retina which is sensitive to light, may be performed as follows: If while in a dark room one looks against a plain wall, and in this position waves backward and forward

a dim light, a candle or a lamp turned low, close to the eye, and under or to one side of it, he will see outlined on the wall a great number of branching figures like the limbs of a dead tree. These figures are produced by the shadows of the retinal blood vessels falling on the sensitive part of the retina, the rod and cone region.

Duration of the Sensation made by Light.—If we look at a bright light and quickly close the eyes, the light is still seen for an instant afterward. If any object, such as a pencil, be rapidly waved in front of the eye, it will be spread out into a continuous figure. These phenomena are due to the fact that the effect of changes produced by the light on the rods and cones remains for a short time—about one eighth of a second.

Fatigue of the Retina.— If one looks steadily at a colored object and looks quickly away at a white wall, he will see the form of the object in its complementary color. That is, if the object were green, the after-image, as it is called, would be red.

The explanation given is that in looking at the green color the part of the eye which receives its image is exhausted for that color, and in looking at white, which has both green and red in it, the green is no longer seen, while the retina is fresh for red color, and reports its presence.

The Advantages of Two Eyes.—By means of two eyes the range of vision is extended; the form of objects can better be determined if the eyes alone are to decide; the distance of objects can better be estimated.

One may easily convince himself of this by looking with only one eye among the limbs of a tree, and attempting to trace their course, and during the process suddenly opening the other eye and noting the greater clearness of view.

One eye will also help out the other when that one is defective.

Defects of Vision.—No eye is perfect. An eye is said

to be *normal* or *emmetropic*, as far as its focusing power is concerned, when it at rest is focused for distant objects (those more than twenty feet away), and has the power of accommodating itself to objects as near as five inches.

Short-sightedness.—An eye is *short-sighted*, or *myopic*, as it is called, when objects must be considerably nearer than twenty feet to be seen distinctly with the eye at rest. Such objects, consequently, are never seen distinctly by a myopic eye without the aid of glasses. The range of near objects may be two or three inches. In such an eye the eyeball is too long, which causes the focused rays from the distant objects to fall in front of the rods and cones, leaving only an indistinct image on them. A concave lens is used to correct this defect.

Long-sightedness.—The long-sighted eye, or *hypermetropic* eye, is one in which the eyeball is so short that when at rest parallel rays are not brought to a focus anywhere in the eye. The function of accommodation is made use of in such an eye to make distant objects distinct, while the limit of the near point is more than ten inches. To read this type, such an eye requires it to be held at a considerable distance. Convex glasses are used to correct this defect.

Astigmatism.—To get a perfect image on the retina the cornea and the lens should be curved alike in their different meridians. Suppose in Fig. 87 (*a*) to be one of the poles of the globe. The meridians would be lines on the cornea corresponding to meridians drawn on a geographical globe. Now, if the cornea or lens were more convex along some meridians than along others, the eye might be long-sighted in one plane, and normal or short-sighted in another.

This would cause indistinctness of some of the lines of the objects looked at. Such an eye looking at a figure made up of lines running in different directions will see some of the lines indistinctly, and if the figure be rotated, he will see others indistinctly when they arrive at certain positions.

Such an eye is called *astigmatic*, and requires glasses ground of the peculiar shape to fit its own special form of astigmatism.

Selection of Glasses.—If one has cause to suspect that his eyes are abnormal in any of the above points, he should not hesitate to procure and wear the proper glasses.

These defects are likely to increase in amount and bring with them other troubles to the eye. Glasses, if properly chosen, relieve the eye, and sometimes to such an extent as to allow recovery.

Muscles of the Eye.—The ball of the eye is made to turn in its socket by six muscles, which are shown in Fig. 89, representing the right eye. There are four straight muscles running from the bottom of the socket, one attached to the upper side, one to the lower side, and one on the inner and one on the outer side. They are called *superior*, *inferior*, *internal*, and *external recti* muscles. These turn the eyeball up, down, to the right or to the left, combining their movements to produce some in intermediate directions. The external rectus is partly cut away in the figure.

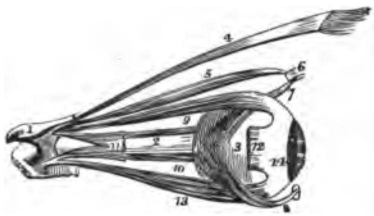


Fig. 89.

Muscles of the Eyeball.

The *inferior oblique* and the *superior oblique* (seen in the figure) rotate the eye in opposite directions. Note in the figure the pulley through which the superior oblique muscle runs.

The Eyelids.—These are folds of the skin so modified as to make the very necessary protecting organs, so easily observed and understood as to need only brief mention.

Just under the skin of the lids are the circular muscles whose contraction forcibly closes them over the eyes. In

the upper lid is a muscle which runs back to be attached in the socket, whose contraction lifts the upper lid.

The upper lid has a plate of cartilage in it to make it firmer.

The skin of the inner surface of each lid is continued on over the front of the eyeball, and is known as the *conjunctiva* (1′ in Fig. 87). It is very sensitive, warning us by severe pain to keep foreign bodies from the surface of the eye.

Tears.—In the upper and outer region of each eye-socket is located a small gland called the *lachrymal* gland, whose function is to secrete a watery fluid, commonly called *tears*. This secretion is constantly produced, and being rubbed over the surface of the cornea by the process of winking, runs along the edges of the lids, and is taken up by the two openings of the lachrymal duct at the inner corner of the eye, and by this tube conveyed to the passage of the nostrils. The duct and its branches at the lids, also the position of the lachrymal gland, are shown in Fig. 90.

Fig. 90.

EYELIDS AND LACHRYMAL DUCT.

The secretion of this small but very important gland is regulated by a special nervous center, which may, through other centers with which it is connected, be affected by various causes. A foreign object on the conjunctiva may make it secrete more abundantly; or stimuli from brain centers, as in emotions, may cause great increase of action.

Directions for Practical Work.

The eye of an animal may be obtained from the butcher. Examine its external surface, and then from a section of it identify as many points in it as possible, as are given in Fig. 87. Several eyes will be necessary to accomplish this well.

Eyes from other animals than the large ones answer well. For example, those of a fish or frog.

The muscles of the eyeball are best studied in position in some small animal.

Examine for comparison the eyes of insects and crawfishes.

If the eye of an ox be prepared by removing the sclerotic coat without disturbing the other coats, and it be placed in the end of a tube so that the back part may be shaded, the image formed can be seen through the remaining parts.

The eye of a cat will show the images without removing the sclerotic coat.

Repeat the experiments to show accommodation, the blind spot, and the retinal vessels, as described in the text.

To show the fatigue of the retina, repeat the experiment with a number of different colored objects.

Review Questions.

1. What are the essential parts of the apparatus of sight?
2. What is said of the visual apparatus of the lower animals?
3. Describe the globe of the eye.
4. Make a diagram showing these parts.
5. Compare it with a photographic camera.
6. What are the lenses of the eye?
7. Describe the cornea.
8. Describe the crystalline lens.
9. Describe the ciliary muscle.
10. How is the image formed in the eye?
11. Where is the image?
12. How must a hand lens be arranged to form an image on paper?

13. What change must be made to accommodate this arrangement to different distances of the object?

14. What part of the eye accommodates it to different distances of objects?

15. Describe the action of the lens and ciliary muscle in accommodation.

16. What are the functions of the iris?

17. How are the motions executed and regulated?

18. Give the position of the retina.

19. Describe its structure.

20. What are the rods and cones, and what is their function?

21. What is said of the action of the light on the rods and cones?

22. What of the degree of sensitiveness of different parts of the retina to different stimuli?

23. Where is the region of distinct vision? Show this to be the case.

24. Where is the blind spot?

25. Construct figures on a sheet of paper to prove its existence.

26. What is said of seeing things in their proper position when the image is really inverted?

27. What of the blood supply to the retina?

28. How may the blood vessels in the retina be shown?

29. What does the experiment prove?

30. What of the duration of the sensation made by light?

31. What appearances are due to this fact?

32. What is the reason that a white object gazed at steadily will appear in black outline if we turn immediately to look at a white wall?

33. Give other illustrations.

34. What are the advantages gained by having two eyes?

35. What is a normal or emmetropic eye?

36. What is short-sightedness, and to what is it due?

37. What is long-sightedness, and what may be its causes?

38. What is astigmatism, and to what is it due?

39. What kind of glasses are demanded in each of the above cases?

40. Describe the muscles of the eye.

41. What are their functions?

42. Describe the eyelids.

43. What is the conjunctiva, and what is its function?

44. How are tears formed, and what is their function?

45. How are they disposed of?

CHAPTER XXI.

THE EAR AND THE SENSATION OF HEARING.

The Sensation of Hearing is usually produced in man by vibrations of air. The effects of these vibrations are by means of a very complicated apparatus brought to bear on the special sense-organ cells of the ear, which may be called the auditory cells.

The essential parts of the organ of hearing consist, as in all other special senses, of three parts: (1) cells which are affected by special stimuli—vibrations in this case; (2) a nerve, the auditory; (3) nerve centers in the brain.

The auditory cells are placed in a watery liquid in the inner part of the internal ear. Being so inaccessible, very great difficulties have arisen in the study of the internal ear. Consequently, the functions of all its parts are not so definitely known as are those of the eye.

The Nature of Sound.—While the nature of sound is better understood if a work on Physics is consulted, a few facts in regard to it are necessary to an understanding of hearing.

The vibrations of the air which produce sound are caused by the vibrations of bodies lying in it. Whenever an elastic body such as a stretched wire, a metal plate, a glass rod, or a strip of wood is struck, the body is thrown into vibrations. These can be seen in a tuning fork, or a piano string, or in a bell. One of these rapidly vibrating bodies strikes against the air in its backward and forward swings. The air is very elastic, and as the side of the vibrating body strikes against it, it is condensed immediately next to the body. But as

the body in its return swing pulls away from the air, it is made less condensed.

This would give a layer of condensed air and one of rare air. But as the air is very elastic, the condensed layer springs out again like a compressed spring, and in doing so strikes against the layer of air before it just as the side of the vibrating body struck it, and thus the conditions are repeated farther on, the condensed layers expanding and the rare ones contracting in turn.

By this means the swinging body comes to have a series of layers of rare and condensed air all around it. If one considers a single part of air, he can readily see that it must by this means be continually moved backward and forward by these motions. These layers of rare and condensed air following each other, and causing every particle of air to swing backward or forward over a certain small distance, are the vibrations which the ear is constructed to detect.

It is customary to speak of sound as moving in *waves*, but these are not like waves of water.

In the chapter on Voice mention is made of what the pitch, intensity, and quality of a sound depend upon. It may be well to refer to this chapter for the definition of these terms for use here.

The Auditory Apparatus.—The whole auditory apparatus consists of three portions: the *external* ear, the *middle* ear, and the *internal* ear, so named from their relative positions.

The External Ear.—This consists of the part which projects from the head, called the *pinna*, and the canal leading from this to the middle ear, called the *external meatus* (Fig. 91).

This canal is closed internally by the membrane of the middle ear, known as the *membrana tympani.*

The Middle Ear.—This is known also as the tympanum. It is an irregularly shaped space in the temporal bone. It

opens by a canal, called the *Eustachian tube* (Fig. 92, *ET*), into the upper part of the pharynx.

It is lined by mucous membrane, which is very thin over the membrana tympani, which separates it from the external meatus.

A connected series of very small bones extends across this cavity from the membrana tympani to a membrane closing one of the passages in the internal ear, the *fenestra ovalis* (oval opening). These are shown in the diagram in Fig. 92. The *malleus* extends by a process over the membrana tympani, to which it is firmly attached.

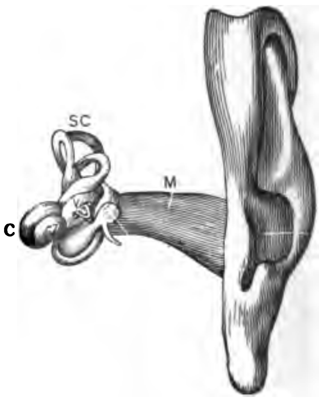


Fig. 91.

GENERAL VIEW OF THE EAR WITH THE TEMPORAL BONE REMOVED.

M, meatus; *SC*, semi-circular canals; *C*, cochlea; *V*, vestibule.

The *incus* fits closely to the malleus.

The *stapes* is attached to one process of the incus by its smaller extremity, while its broad foot is attached to the membrane which closes the fenestra ovalis.

Certain small muscles are arranged to tighten or loosen the membrana tympani and the pressure of the stapes on the fenestra ovalis.

Functions of the External and Middle Portions of the Ear.—The internal ear, in which are the auditory cells, is filled with a liquid which must vibrate in order that these cells may be stimulated. Air is extremely light, and its vibrations acting directly on so heavy a body as water would have but little effect.

It is the principal function of the external and middle ear to direct and intensify the vibrations of air so as to set the liquid in the internal ear to vibrating.

The Pinna and the External Meatus serve to direct the vibrations to the membrana tympani, and also slightly to increase their intensity. The effect of funnel-shaped tubes in this regard is shown by the ear-trumpet.

The Membrana Tympani.—In the study of sound, physicists have found a thin membrane to be one of the most effective means of catching up vibrations of the air. The *membrana tympani* serves that purpose in the ear. A very small muscle regulates its tension.

The Function of the Bones.—The long process of the malleus attached to the membrana tympani is the long arm of a lever, which, when pulled forward and backward by the vibrations of the membrane, first acts on the incus, and then the stapes, and by this means the liquid in the internal ear is acted on with considerable intensity by the foot of the stapes. In this way the very light air is made to move into vibrations the comparatively heavy liquid in the internal ear.

The Eustachian Tube.—This passage from the middle ear to the pharynx allows of an equal pressure of air on both sides of the membrana tympani. It also permits the outward passage of secretions of the middle ear, and, unfortunately, sometimes allows affections of the mucous lining of the pharynx to extend into the middle ear, with serious results to hearing. If one closes his nostrils and mouth, and attempts to force air out, he will feel a pressure on the membranes of the middle ear.

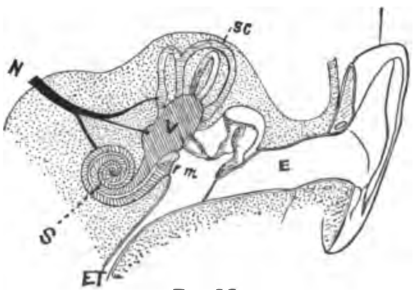


Fig. 92.

DIAGRAMMATIC SECTION OF THE EAR.

E, external meatus; *M*, middle ear, showing the bones—the foot of the stapes is against the *fenestra ovalis*; *r*, fenestra rotunda; *SC*, semi-circular canals; *N*, auditory nerve; *V*, vestibule.

The Internal Ear.—The internal ear consists of a group of small membranous tubes filled with liquid, which lie in another liquid contained in a corresponding group of bony channels, hollowed out of the base of the temporal bone. These tubes are called the *labyrinth*.

Three parts of the labyrinth are recognized: The *semicircular canals* (*SC* in Fig. 91); the *vestibule*, *V*, and the *cochlea*, *C*.

The passages of the bony part of the labyrinth open together. The canals and cochlea may be considered as branches of the vestibule.

The Cochlea.—The cochlea is a spiral tube with two and one-half turns, and as it is supposed to contain the auditory cells, it needs at least a brief description.

The tube of the cochlea is internally partitioned off into three divisions. In Fig. 92 the diagram shows by different shading the three tubes running side by side at *S*.

One is connected with the vestibule, and for this reason is called the *scala vestibuli;* another is seen at the *fenestra rotunda*, having only a thin membrane between it and the tympanum, or middle ear. It is named the *scala tympani*. Between the two is the middle tube, the *scala media*, or *cochlear canal*, represented in the figure by the small unshaded coil. The scala media is the true organ of hearing.

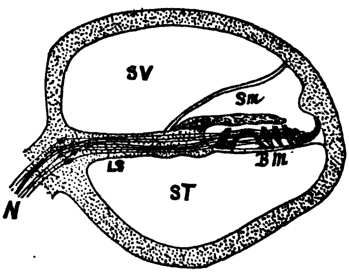


Fig. 93.

SECTION OF A TURN OF THE COCHLEA, MADE THROUGH *S* IN FIG. 92.
For explanation see text.

In the figure referred to these tubes are represented in a purely diagrammatic way.

Fig. 93 shows a cross-section of the three tubes, which may be considered as taken from *S* in Fig. 92. In this sec-

tion the letters *SV* are placed in the scala vestibuli; *ST* in the scala tympani, while *SM* is in the cochlear canal, or scala media. A branch of the auditory nerve reaches the base of the core around which the tubes are wound. Its fibers ascend this core and are distributed to the cochlear canal through the partition between the scala vestibuli and the scala tympani. This partition is of bone. It extends as far as the cochlear canal, and is called the *spiral plate*, or *lamina spiralis*, marked *LS* in Fig. 93. A few nerve fibers, *N*, with a group of nerve cells, are shown in the figure.

The Cochlear Canal.—If the nerve fibers are traced from the spiral plate they will be found to end in certain cells in the cochlear canal. These are supposed to be the *auditory cells.* They rest on the membrane which continues out from the spiral plate and makes one side of the cochlear canal. This membrane is called the *basilar membrane* (*BM*). The auditory cells have about them various other cells and parts, some shown in the figure.

How the Auditory Cells are made to Vibrate.—The scalæ tympani and vestibuli have a liquid in them which through the scala vestibuli is in connection with the liquid of the vestibule.

This liquid, it will be remembered, is in direct contact with the membrane to which the stapes is attached.

When, then, this bone is put in vibration, the liquid in the two scalæ is made to vibrate also, and this in turn transmits its vibrations to the basilar membrane. As the auditory cells rest on this, they are affected, and impulses are given to the nerve fibers, which, conducted to the brain, produce the *sensation of sound.*

The usual source of the vibrations is the air, yet the liquid of the internal ear may be made to vibrate through the bones of the skull, and the sensation of sound thus produced. This may be experienced by scratching with a pin

on one end of a wooden object while the other end is held between the teeth.

Determination of the Pitch, Intensity, and Quality of Sounds.—Every vibrating cord, like a pendulum, can only vibrate at a certain rate, as one person giving motion to another in a swing must time his pushes to the rate of the swing, or he will check instead of increase the motion.

From this fact it comes about that if a sound is made near stretched strings of various lengths, only that string will take up the vibrations which has the same rate. It, of course, then repeats the same note. Other strings would repeat other notes, and if a large number were together, any note sounded might be repeated. This actually happens when another instrument is made to play a tune near a piano. Now, the basilar membrane is so suspended as to act as a very great number of strings of shorter and shorter length toward the narrower end of the cochlear canal, while the auditory cells resting on it throughout its length report through their nerve fibers its every vibration.

As the pitch of a sound depends on the rate and intensity in the force of the vibrations, and the quality on the combination of the different tones in every sound given off by vibrating bodies, it would seem that parts of the cochlear canal are sufficient to determine each of these properties of sound.

Functions of the Semi-circular Canals.—Both the membranous semi-circular canals, and the little sac into which they open receive branches of the auditory nerve, as shown in the figure, but it still remains unknown what their real functions are.

There are good reasons for believing that the semi-circular canals are organs by which we are made aware of any change of the position of the body.

Every one knows that even with his eyes shut he can tell when he is falling over in any direction. It is thought that

this sensation of a change of position of the head is caused by the liquid in the semi-circular canals being disturbed by the motion of the head, and in consequence pressing on the sense-organ cells lining their walls. From this view of the canals they have been called the *organ of equilibrium*, or the *balancing organ.*

Ears in the Lower Animals.—Among the lower animals the auditory organs may be seen in a series from a very simple minute open sac with sensory nerve fibers distributed to its lining cells, ascending through all grades of simplicity and complexity up to the complex organs of which we have taken but a very brief survey. In the higher vertebrates the principal differences in their ears from that of man is in the difference of the development of the cochlea, and in different shapes of the pinna.

The ears in the invertebrate animals are often in other parts of the body than the head.

Directions for Practical Work.

The middle ear with its bones and membrane can be shown in the head of any of the common animals killed by the butcher.

The head of a rabbit or any other small animal gives less trouble.

The internal ear is more difficult to dissect, but any one can accomplish it, and will be fully repaid for his trouble.

In the frog the smooth round spot on either side of the head is the membrana tympani, the outside of which is continuous with the skin. By examining it from the inside of the mouth, the Eustachian tube is seen to be a wide opening.

The frog does not possess the series of bones, but a little rod takes their place.

Review Questions.

1. How is the sense of hearing produced?
2. What are the essential parts of the organ of hearing?
3. How is sound produced?

4. How is a particle of air moved by sound?

5. What are the general divisions of the auditory apparatus?

6. Describe the external ear.

7. Describe the middle ear.

8. What are the bones of the ear and how are they arranged?

9. What muscles are in the middle ear and what are their functions?

10. What are the functions of the external and middle ear as a whole?

11. What are the special functions of the pinna and external meatus?

12. What is the use of the membrana tympani?

13. What is the action of the series of bones?

14. What are the parts of the labyrinth?

15. How are the membranous canals arranged?

16. Describe the cochlea.

17. Show with a diagram how its tubes are arranged.

18. Where are the auditory cells?

19. Where are the fibers of the auditory nerve?

20. How are the auditory cells made to vibrate?

21. Under what conditions will one vibrating body repeat the note made by another?

22. How is it thought that the pitch, intensity, and quality of sounds are determined in the ear?

23. What is said of the functions of the semi-circular canals?

24. How are they supposed to give rise to the sensations?

25. What is said of the ears of the lower animals?

CHAPTER XXII.

HEALTH AND DISEASE.

General Considerations.—An intelligent conception of the parts of the body and the conditions under which they work will suggest in each case the rules which should guide the care of the part.

However, there are certain points of such vital interest that perhaps it would not be out of place to repeat them by way of emphasis in this special section.

Air.—We have seen that the life and activity of every cell in the tissues depend constantly upon oxygen, and that to obtain it we must have good air. This is not simply desirable, but it is an absolute necessity to good health. As the subject was discussed in greater detail under Respiration, the discussion need not be repeated.

As the tissues depend solely on the lungs and the organs of respiration to furnish this supply, nothing must be done to interfere with their action. Clothing that limits either the respiratory acts or the circulation of the blood can not be too strongly condemned.

Food.—We have also seen that with the oxygen there must be supplied proper foods to the cells. The elements necessary in these have been also discussed in detail. As foods are substances which appeal to the eye and the nose, and are always tasted in eating them, we are less likely to make mistakes in regard to them than we are in regard to the purity of the air which may change so gradually as not to be perceived. People who would not take food with a spoon just used by another will often submit to the breathing of foul air.

The greatest danger to health in regard to foods is that the gratification of the very sensations which are absolutely necessary in the selection of food, and in determining the quantity to be taken, may become the sole cause for taking the food and drink as well. In such a case abnormal tastes may be developed, and the only safe guide given us in this matter is greatly disturbed in its functions, with the sure result of greater or less injury to health.

A very great number of the common disturbances of health, some of them serious, and some even fatal, arise from simply eating for the sensations the act gives to the eater.

Drink.—We long ago learned by our thirst that the body must have water. We have seen that the various processes of the body depend largely upon the presence of water for their action. But all that is necessary in the drink is water. Often the water is flavored with other substances, which may be harmless in some cases, but in many they are injurious, and in no case are they of any great benefit.

These are mainly but answers to the demand of tastes that have been cultivated.

Source and Composition of Alcoholic Drinks.—Alcohol is a liquid arising by the process called fermentation in solutions containing sugar. When the alcohol is separated in a pure state from the remaining parts of the solution, it is found to be a transparent liquid. This is called absolute alcohol. It is lighter than water and will mix readily with it. It burns with a blue flame without smoke. It dissolves very many organic substances. It is used very extensively in the arts as a solvent, in making extracts of substances, and as a fuel in alcohol lamps. It is also used largely in the preservation of museum specimens. Its chemical symbol is C_2H_6O.

The process of fermentation which produces alcohol is the result of the growth of a very minute plant seen only by the aid of high powers of the microscope, the

yeast plant. During the growth of the yeast plant, the sugar in the solution is changed into alcohol and carbonic acid.

Juices of ripe fruits have sugar dissolved in them. The yeast plant growing in them changes the sugar into alcohol and carbonic acid. The latter as a gas bubbles up through the liquid and passes away; the alcohol remains. Thus wine is made. In the same way the juice of apples turns to cider. Thus the juices of various fruits may change to various alcoholic drinks, differing in flavor according to the fruit from which they are made. In all, the alcohol is just the same in composition and properties. In such drinks as beer, ale, and porter, which are said to be "brewed," the sugar is obtained by sprouting certain grains, mainly barley, which is then dried, ground, mixed with water, and kept moderately warm. Yeast is placed in the mixture, and during its rapid growth produces alcohol. From the mass the liquid beer containing alcohol is separated.

Thus, in one way or another, the yeast plant growing in sugar-containing liquids produces alcohol in these liquids, and from them are obtained the various forms of alcoholic drinks. In all of these it is the alcohol which is the ingredient which produces intoxication and most of the other effects discussed here. The amount of alcohol in the different alcoholic drinks varies very greatly, being as low as two per cent in some kinds of beer, and rising as high as fifty-five per cent in some forms of rum or brandy.

Liqueurs are formed by mixing in certain proportions various alcoholic drinks, or by adding to them aromatic or other substances, with the object of producing some peculiarly pleasing flavor. These vary very much in the amount of alcohol they contain.

Often alcoholic drinks formed as above described are adulterated in various ways, the object generally being to make the cheaper ones resemble those more expensive. Things

added in this way may be harmless, but it is well known that many of them are very harmful.

Physiological Action.—The habits of drinking liquids containing more or less alcohol, and of using tobacco, tea, coffee, and opiates, are of such wide extent, and may be accompanied by such serious evils, that it is of the utmost importance that the young be guarded as far as possible against forming them.

The following is a brief outline of the physiological effects of these substances as far as physiologists understand the matter. It must be remembered, however, that the determination in detail of the physiological effects of any substance, whether that substance is a food, a drug, or a poison, is an exceedingly difficult matter. We know the *general* effects of many of these substances well enough to rely on them to help us get well in cases of sickness, or to avoid those which are poisons, without knowing in any definite manner the way in which the *particular* substance in question may act.

For example, it is known that in some malarial diseases, quinine, given in a certain way, will in a large number of cases bring about a cure. But no one, except one who has a very superficial knowledge of the subject, would have the confidence to assert definitely the exact effect of quinine on the respective organs or tissues of the body, or on the cause of the disease. Nor have any microscopic sections of the tissues, however skillfully made, been able to demonstrate the effect on them of quinine taken in quantities sufficient to produce a cure.

Or, to take another example: it is known that strychnine is a violent poison. Taken in even very small amounts, it brings about death in a very short time. The general symptoms of strychnine poisoning are well known, and it is said further, as a partial explanation of some of them, that it has the effect on the spinal cord of throwing it into a highly sensitive state. In this condition the slightest afferent

(sensory) nervous impulses will produce profound reflex actions, and consequently a touch will send the animal poisoned with strychnine into violent spasms.

And in addition, after long experimentation, a few other rather vague statements can be made about the specific effects of the poison. But, powerful as the poison is in its influence on physiological action, it is extremely difficult to decide what particular effects it has on each organ. It is impossible to demonstrate by histological sections what changes it produces in the tissues.

While these facts are true of quinine and strychnine, whose particular uses and dangers are so well known, still more are they true of the hundreds of other substances used as medicines or shunned as poisons.

Thus it is with alcohol, tobacco, tea, coffee, and opium. It is difficult, and in most cases impossible, to decide just what, if any, effect the use of alcohol has on any particular tissue; for example, the bony or the muscular tissue. But the general effects on the body as a whole, or on the character of the individual, may be plain enough.

If it is clear that the continued use of alcoholic drinks may very often have the most serious effects physically, mentally, and morally, the fact that we cannot trace with certainty the exact physiological and histological steps by which the user of alcoholic drinks reaches this state of physical, mental, or moral degradation need have no significance for us as moral beings.

We would be as unwise to regard alcoholic drinks with favor because of our ignorance about their specific physiological effects, as to view strychnine in the same light because of a like ignorance of its specific action on the tissues.

On the other hand, we certainly gain nothing in our fight against the use of alcohol by asserting specific effects on the tissues which can easily be demonstrated not to exist.

The effects of alcoholic drinks may be classified as follows:

a. Effects on the body, including immediate effects and those of a more permanent nature.

b. Effects on the mental and moral nature.

c. Results on the community as a whole.

If a considerable dose of pure alcohol, or even a very strong solution of alcohol, were taken, it would produce death in a short time. Strong alcohol applied directly to living tissues abstracts much water from them, kills the living cells, and coagulates the proteid substances. The action is a violent one. If alcohol were only taken in this manner, it would demonstrate quickly enough its poisonous nature, and there would be no need of pleading against the formation of this evil habit.

But, as alcohol is used in drinks only in more or less diluted solutions, such violent effects do not appear; but results of quite a different nature follow slowly, and may pass away, the worst coming to remain only after a prolonged use of such drinks.

Thus it comes about that some of the most dangerous results of the use of alcoholic drinks are not always clearly traceable by the victim, or even by his friends, to the true cause. It is thus that alcohol may become a slowly acting, insidious poison, whose cumulative effects are to undermine the system, and render it incapable of withstanding the diseases ever lying in wait to attack the body.

Indeed, the final outcome may not be a direct result of the alcohol. While in such a case the alcohol is not the immediate cause of the fatal ending, it is certainly the first cause. Still, being thus far removed, it often escapes the blame. This makes it all the more a dangerous enemy.

People usually begin by taking alcoholic drinks only occasionally, and in such moderation that few evil results are directly traceable to them; the next stage is the habitual though still moderate use of such beverages; and this is apt

to develop finally into the last stage in which the use is excessive as well as habitual. Hence, though the immediate physical results of the first drink may be insignificant, it is evident that the moral effects may be incalculable.

It should be repeatedly emphasized, then, that the use of alcoholic drinks in the great majority of cases creates a demand for their increased use. With some this thirst may not increase immoderately, and may be kept under control, but this cannot be determined beforehand; and in thousands of cases this artificial thirst grows until it is beyond control, and thus results not only in serious harm to the body and mind of the victim, but also brings misery, unhappiness, and suffering upon his family and friends.

In discussing the effects of any kind of medicine, food, or condition on the body, we should always take into consideration the fact that different individuals are very differently affected by such conditions. A substance which is generally recognized as a good food may be very unwholesome for certain individuals; conditions which will maintain and improve the health of one may break down the health of another; a drug which can be given to some with marked beneficent effects acts on others as a real poison. In the same individual we may find great differences in this respect in health and disease. In other words, human bodies are not like a number of sewing machines turned out by the same firm, but are very complex organizations, made up of extremely complex materials but little understood, and put together by laws of which we are totally ignorant. The result is that no two human bodies are exactly alike either in form or power. To this fact is due much of the difference of opinion in regard to the exact effects of certain things on the body. It would be dangerous to assert in a great number of instances that a thing was universally either beneficial or injurious simply because it affected certain individuals in one way or the other.

If a small amount of alcohol be taken in a drink, there may be no perceptible effect except a slight increase of the rate of the pulse. The effects of large amounts of alcohol are summed up by Dr. E. W. Emerson as follows:

"If large doses be given to a healthy person, the usual course is first a flushing of the face, with a greater flow of words and ideas, and tendency to muscular activity, then imperfect articulation, loss of judgment, unsteady gait, dulled moral sense, irregular eyesight, loss of sensation, then of consciousness, and finally even impaired (vegetative functions) breathing and circulation; all of these phenomena being successive paralyses of nervous centers of brain, medulla, and spinal cord.

"If large doses be often repeated, the alcohol carried through the various organs modifies their nutrition and the growth of the mere connecting tissues (frame-work) at the expense of their more important special tissues. Thus the stomach and liver, kidneys and nervous system are all injured; and finally even the voluntary muscles, and the all-important involuntary muscle called the heart, degenerate. These processes are slow and only result from the decided abuse of alcohol, especially spirits."

It has already been indicated in the chapters on the circulation (p. 105), digestion (p. 150), the kidneys (p. 199), and the nervous system (p. 244), what are some of the special results of the continued use of alcoholic drinks on the organs there treated of.

To appreciate more completely the full effect of alcoholic drinks, we must consider the effects on the system as a whole. If the important functions of our organs are interfered with for any length of time, the constitution becomes undermined, impairing the powers of the body, rendering it liable to attack by disease, and unable to rally from such attack by its normal vitality. When accidents occur rendering surgical operations necessary, it is well known that the patient, if he

has been an habitual user of alcoholic drinks, has less chance of recovery, or recovers more slowly, than the abstainer.

Life insurance companies have investigated this subject from a business standpoint. They recognize the importance of these facts by regarding persons addicted to the use of alcoholic drinks as of greater risk. Also those who go into training for athletic contests are required to abstain from the use of alcoholic drinks, it being recognized that these interfere with success where strength and endurance are requisite.

Alcohol as a Medicine.—In regard to the use of alcoholic solutions as a medicine in the treatment of diseases, it is obvious that this is not the proper place to discuss such a question. When attacked by a disease we should put ourselves into the hands of a capable physician, and then trust to his learning and skill. Well-known poisons are frequently administered as medicines, but such substances should be taken only under the direction of a physician. It is usually dangerous to follow the advice of those who have not had special training and experience in the treatment of disease. Still it may be of interest in this connection to say that among high authorities there is a great difference of opinion in regard to the value of alcohol in disease.

There are those who regard it as of great value in certain diseases, while there are others, and we are bound to admit that the number seems to be increasing, who believe that it is harmful in these diseases, and of little or no benefit in others. But, as just stated, this is a question to be settled in the future by skilled physicians, and it does not affect the one we are considering here, of the danger of forming the habit of drinking alcohol.

Other Substances in Alcoholic Drinks.—In the various liquids which are allowed to ferment and from which wines, beers, whisky, etc., are made, many other substances exist. Some of these, such as fusel oil in whisky, and certain ethers in wine, have been isolated, and their properties

have been studied, but there are still many whose characteristics have not as yet been determined. To some of these substances are due the different aromas and flavors that distinguish one kind of alcoholic drink from another. Many of these substances are undoubtedly injurious to the body, and some are known to be poisons. While it is also true that some of the ingredients in these drinks are known to be beneficial or even nutritious, their mixture with the injurious substances renders them of little use. But no one claims that he takes these drinks for the very small amount of nutritious substances which they may possibly contain.

Thus far we have spoken of the effects of alcohol on the general health of the body. But there is one effect that needs neither physician nor physiologist to emphasize its evils. That is the *intoxicating* effect of large doses, what is known in ordinary language as "getting drunk." The evils of drunkenness are so great and so well known that we need not dwell on them here. Every community has too many sad examples of the misery and unhappiness which has this for its cause. Happily a large number who habitually use alcoholic drinks do not reach the stage of habitual drunkenness, but it is well to keep in mind that such an end is a possibility. It is only from the ranks of those who use alcoholic drinks moderately that the large army of drunkards is recruited. There needs no demonstration here of the moral degradation accompanying habitual drunkenness. The facts are unfortunately too evident in every land.

Effects of Alcoholic Drinking on the Community.— The statistics of every prison, insane asylum, and almshouse have shown over and over again that alcohol is the greatest cause of crime, insanity, and poverty. Most other poisons and diseases with greater or less swiftness kill their victims, but leave them harmless as they carry them along to their fatal ending. But alcohol often renders its victims, after they have reached a certain stage, the enemies of mankind, makes

them active agents in the community in undermining its morals, in increasing the misery and suffering of its members, and in adding to the list of its most flagrant crimes. The associated vices of drunkenness, and the evil influences which extend from many of the drinking customs and drinking places, tend to make alcohol as serious a menace to the health of the community as a whole, as it is to the health of the individual.

Tea.—Tea consists of the dried leaves of a plant extensively cultivated in China, Japan, Ceylon, and India. These leaves contain a number of vegetable substances common to all leaves, but in addition they contain an alkaloid known as *theine*, which is characteristic of tea leaves. There is also a large amount of *tannin.*

Theine is exactly like *caffeine* (found in coffee) in composition, and apparently has the same physiological effects as are assigned to that substance ; that is, it is a stimulant to the nervous centers. The considerable amount of tannin in tea has an injurious effect on the digestive processes.

After speaking of the beneficial effects of a moderate use of tea for some persons, Dr. Yeo says :

"On the other hand, it is quite certain that tea taken in excess, and in some constitutions, may become very injurious. It will not infrequently excite and maintain most troublesome gastric catarrh, the only remedy for which is an entire abstinence from tea for a considerable period. It is often also the cause of troublesome cardiac palpitations, together with muscular tremors, and general nervous agitation. We have noticed that tea will often commence somewhat suddenly to disagree with a person, and excite dyspeptic symptoms, coincidently with the occurrence of nervous worry, and that after the cause of the nervous worry has passed away tea may again be taken in moderation with impunity. In irritable states of the stomach tea is also apt to disagree, especially if the coarser teas containing much tan-

nin are taken ; these, when taken in large quantities during or too soon after a meal, will disturb and often seriously hinder the digestive processes."

The beneficial effects which are thought to belong to the moderate use of tea and coffee are no doubt often more apparent than real ; they produce an agreeable feeling, which makes the user believe that he is benefited when perhaps only a harmful change has taken place.

If no other harm came from the use of these substances than the constant deception as to the true state of the body, even that would be considerable damage. For, if the proper appetite is interfered with, it is quite certain that at times too much or too little food will be taken. Tea and coffee have also the power of relieving the sense of fatigue, and while they may thus be valuable aids as a temporary relief from suffering, they become very harmful if they lead us to overlook and disregard the cause of the fatigue. Fatigue itself has its uses, and we would sooner or later suffer if deprived of its warning voice. In other words, the delicate balance of coördination between the processes of nutrition and necessities of the various organs would be lost. Such a state continued cannot result otherwise than injuriously, the extent of injury depending on the degree to which the organism is affected. The claim that tea or coffee will enable the body to do more work on a smaller amount of food is absurd. Energy cannot come from nothing. As the source of energy in the body is oxidation of oxidizable substances (foods), it is impossible for a substance to cause work to be done by doing away with its source of energy.

It is unwise to use even in so-called moderation these stimuli which thus distort the natural action of the nervous mechanisms regulating the nutritive processes. But it is worse than folly to indulge in them to an excess which brings on one the most serious results. Between moderation and excess the gradation is very gradual. Moderation in the

great majority of cases becomes a greater or less degree of excess. It is certainly the part of wisdom to forego the passing pleasure that these beverages may give, and avoid the risk of the more lasting suffering or disability which their use may entail.

Coffee.—Coffee consists of the seeds of a plant which is cultivated extensively. The seeds, or berries as they are called, are roasted, and by this process an aromatic substance is developed which gives the coffee its flavor. The principal ingredients in roasted coffee are this *aromatic substance*, which is volatile and may disappear in time, *tannin*, certain *vegetable acids*, and *caffeine*. The last named belongs to the group of chemical substances called *alkaloids*. It is thought that it is the caffeine in the coffee that produces the peculiar effects; but it is claimed that these effects are also due to the aromatic substance or substances produced in the roasting.

Physiological Effects.—The most obvious effect of coffee is its stimulation of the nervous centers. It is also said that caffeine increases respiration and the blood pressure. A large dose may so affect the circulatory organs as to accelerate the pulse or even make it intermittent. Its effect on the kidneys is to increase their secretion.

In excess, coffee acts as a poison, seriously affecting the heart, producing muscular tremor, and causing disorder of the nervous and digestive systems. In many persons coffee produces dyspepsia.

Tobacco.—Tobacco, as is well known, consists of the leaves of a plant which is raised in many warm countries. It is used in the form of snuff, or is chewed, or smoked as cigars, cigarettes, or in a pipe. It was introduced into Europe at the time of Queen Elizabeth by Sir Walter Raleigh, who learned its qualities from the Indians of North America. From this time its use gradually spread throughout the civilized world. Among the many substances in the leaves of

the tobacco plant the most characteristic is *nicotine*. This is oily and aromatic. It is distilled from the leaves by the heat of the burning tobacco. The vapor of this oil is partly condensed in the cigar or cigarette, or in thc bottom of the bowl or along the stem of a pipe ; but part of it passes on to the throat and lungs of the smoker.

From these regions it gets into the body. Nicotine is an active poison even in small quantities. The amount that usually gets into the body by the user of tobacco is very small, otherwise the results would be fatal. As it is, many persons use tobacco for many years, apparently without bad effects. The body, which at first was greatly shocked at the introduction of the poison, seems later to adapt itself to its presence. Still to a great number of persons it is always a poison more or less undermining the health, or even breaking it down entirely ; used in excess—and there is constantly this danger—the results are most serious. The physiological effects of tobacco are as follows:

It affects the heart so that excessive use may produce palpitation and weakening of the heart, it interferes with the digestion and causes a loss of appetite. A long series of carefully conducted experiments show that immediately after smoking there is a marked loss of the power of doing work with the voluntary muscles. It is said to interfere with the development of the red blood corpuscles, whose great importance has been shown in another place.

Of the other substances besides the nicotine which are vaporized by the heat of the burning tobacco, and pass with the smoke into the mouth, throat, and lungs, some produce irritation of the mucous lining and may bring about a diseased state of those organs, such as a chronic sore throat, and other affections. It is thought that many cases of cancer of the mouth can be traced to the habit of smoking. It is agreed on all sides that the use of tobacco is very injurious to the young, and should be avoided by them in every form.

There have been many cases recorded of death of young boys through nicotine poisoning from excess in smoking.

The evil effects of tobacco come on in such an insidious way, that very often the sufferer has no hint of the true cause of his troubles; this renders it all the more a dangerous enemy.

The tobacco habit grows on one till it becomes in the great majority of cases a somewhat tyrannical master, demanding great sacrifices of time, health, and money to satisfy its desires. This itself is a form of disease. There is another point of view we should consider. How will it affect our associates? Both smoking and chewing are offensive to most people who do not use tobacco. We might well hesitate before forming a habit which will render our close presence disagreeable to many, if not most of our friends.

Opium.—Opium is obtained from the juice of a species of the poppy. The juice is dried, and forms a waxy mass which contains many substances. The characteristic one of the group is *morphia*. This substance is very much used in the practice of medicine. It is, however, such a dangerous poison that it should never be administered in any of its forms except by the advice of a capable physician. A very small amount of any of the common compounds containing this drug is an overdose which will produce death.

The most common forms under which it and its compounds are sold are, opium, laudanum, paregoric, Dover's powders, morphine, and codeia. While morphia is of great service in disease, its habitual use is followed by the most serious results. Unfortunately this usage of morphine is of very wide extent. The repeated use of morphia soon creates an appetite for it, hard to resist, and often wholly beyond control. It mainly affects the nervous system, and through it the whole body. The various disorders gradually following on the habitual use of opiates show themselves in disturbed functions of the digestive organs, of the liver, of the skin, and in the deterioration of the muscular tissue. The most serious

symptoms are those of the nervous system, which is finally completely wrecked, when death comes as a relief to the suffering of the victim. On account of the power of allaying pain and soothing irritation, compounds of morphia are much used in cough medicines, troches, lozenges, and "soothing syrups." As in these "patent medicines" the presence and amount of the opiates is unknown, they become very dangerous and should never be used. Indeed, no medicine should be used whose ingredients are not known, and which is not given under advice of a physician: but least of all should we tamper with one which is suspected to contain so dangerous a poison as opium.

In the close competition of all the pursuits of life, the success which we attain depends on the equipment we bring to our work. Whatever other preparation we may find necessary for any calling, an element which will figure largely in our success is the strength and health of our body. The state of the body conditions what we accomplish. Many are unfortunate in coming into the world with weak or defective constitutions. Others, through accident or disease, have had the powers of their bodies impaired. We feel the greatest pity for such people, and we do what we can to aid them in their efforts to counteract the effects of their disability or to regain that great boon, health.

But how foolish is he who *deliberately* handicaps himself in the race by taking on himself habits which have been demonstrated to be a real injury to him, which may not only tend to interfere with his success, but which may result in the worst consummation, and may make his life a wreck.

To the young who are yet clear of these encumbrances, whose bodies are free from these poisons and their results, the appeal cannot be made too strongly to keep entirely away from them. The only safe course is total abstinence.

We have seen how, through the digestive organs and the lungs, the materials for the growth and repair of the body,

and the chemical substances whose changes furnish its energy, come in; how by the organs of circulation they are distributed to the tissues; how the circulation gathers up, and the lungs, skin, and kidneys dispose of, the wastes, and thus the sense organs, brain, and muscles are kept clean and well supplied for perception, thought, and action.

How important it is for the best perception, thought, and action that one is capable of, that these processes be undisturbed in their normal functions! How unwise, to say the least, is it to interfere with the delicate mechanisms on which so much depend our chance of success and our capability of happiness!

The Germ Theory of Disease: Bacteria.—The improvement of the microscope has allowed a more careful study of the minutest organisms. Besides the one-celled plants and animals spoken of and figured in the first part of this book, immense numbers of other forms, very much smaller than these, have been discovered.

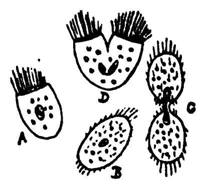


Fig. 94.

SOME OF THE LARGER FORMS OF ONE-CELLED ANIMALS FOUND IN DECAYING LIQUIDS, HIGHLY MAGNIFIED.

The bacteria in the same liquid would be no larger than the small points in these figures. *C* and *D* show forms dividing into two.

If any organic substance, such as a piece of meat, of bread, or a part of a plant, be allowed to remain in a glass of water in a warm place for a few days, the water around the substance will become cloudy, and it will send out an unpleasant odor.

Now, if a drop of the cloudy part of the liquid, or of the scum from the top, be placed under a good microscope, a great number of organisms may be seen. Some that may be seen will be very large compared with the rest. They will be making so much commotion that the smallest may be overlooked. Fig. 94 shows some of the largest ones. If, now, these are allowed to become quiet, or a drop secured with none of the largest forms in it, a very good lens will show

immense numbers of very minute bodies, minute even beside the microscopic bodies just described. They will appear as little points or very short lines. Many of them will be in active motion. Their numbers will be millions. These minute things are one-celled organisms. Whether they are plants or animals has not been decided. They are called *bacteria*, or *microbes*, and are generally referred to as plants. Wherever putrefaction is going on they are very abundant. Indeed, it is their life and growth that cause organic substances to decay or spoil, as we say of meat or of fruit; or *rot*, as we say of any organic substance.

Now, just like larger plants or animals, there is a great number of kinds of bacteria; and, further, like larger plants, some are perfectly harmless to man, and some are very dangerous.

The kinds that could be seen in the preparation described above would in all probability be of the harmless kinds. These are everywhere. When the liquids in which they are growing dry up, these little organisms being very minute, float away in the air. Many kinds may be found in the air, in our food, and in most of the water we drink. They are in our mouths, on our teeth, and in immense numbers in the contents of the alimentary canal.

Thus it comes about that whenever an organic substance is kept moist and warm a short time the great numbers of bacteria scattered all over it begin to grow, and, like other one-celled organisms, they multiply very fast, by each one dividing in two, and so on, until the whole substance is infested with them, and finally it is really consumed by them.

Canning fruits, preserving meats and other foods, is in every case a means of killing the bacteria in the substance to be preserved, and in preventing any others from reaching it. Every bit of food exposed is like a field full of seeds, which only waits for warmth and moisture to make the seeds germinate.

Dangerous Bacteria.—Now, as was just said, a number of very dangerous bacteria exist, which, when they gain access to the tissues, may grow in the living tissues and in the blood, and as the result of their growth produce some of the worst of diseases. They might, in some regards, be compared to those plants which, as parasites, grow on other plants, in some cases to the destruction of the host.

As the knowledge of these dangerous bacteria is only of recent growth, it can not be said definitely just how many diseases are due to them, but it is now generally agreed that certain diseases are thus caused, and the probability is that many of them have this origin.

Among the lower animals which allow of the most definite experiments, a disease called *splenic fever* is known to be so caused, also that of *chicken cholera.*

Diseases Caused by Bacteria.—It is probable that such infectious diseases as small-pox, scarlet fever, diphtheria, and measles, each have for their cause a specific kind of minute organism, which, on gaining access to the parts affected, produces severe results.

It is also probable that such diseases as typhoid fever, consumption, cholera, yellow fever, blood poisoning, and the various forms of malarial fevers, are each due to a specific microbe.

If the exact nature of each disease-producing organism were known—that is, just how it grows—what would kill it or prevent its spreading, we could better control the spreading of these diseases.

Enough is already known in the fact that they are living organisms, subject to the same general conditions as other living organisms, to point out in a general way at least what to do toward lessening the danger from them.

Most intelligent sanitary regulations have for their object the combat with this class of organisms. They include, in infectious diseases, the disinfection of all objects that come

in contact with the sick, by either heating them to a high temperature, or by washing them with a solution of some poison, as carbolic acid, or corrosive sublimate, or by immersing them in some poisonous gas, such as that arising from the burning of sulphur.

In all these cases it is sought to kill the living organisms, which can not survive heat or poisons. Disinfection of sewers has for its object the same end.

That these directions often given should be carried out with intelligence requires some knowledge of the nature of the object to be gained.

The knowledge of the existence and nature of these minute organisms has made it possible to very much reduce the ravages of diseases.

Cleanliness.—This knowledge shows how essential it is to good health that cleanliness of the person, the clothing, the house, its neighborhood, and the whole community, should be the object of constant watchfulness.

Isolation of Those Suffering from Infectious Diseases.—The above facts show also the great importance of careful and complete isolation and thorough disinfection in the cases of diseases which can be communicated from one to another. Carelessness in this respect should be regarded as criminal.

Disease to be Prevented.—Disease is not an evil spirit of whimsical nature that seizes whom it will without cause, but it is the result of the action of definite laws. To deal with it in a rational method, we should at least make use of the few facts that are known.

These show us that in many cases, at least, disease is caused by the growth of organisms in the tissues or liquids of the body. The body is the field, they are the seeds. If the seeds never reach the field they will never grow. If when they reach the field they find it well prepared for their reception, they will quickly occupy it. If, however, when they

come, they find the field in an unfavorable state for their germination, they will not grow.

Cleanliness of air, of food, of water, of the person, and of the surroundings, may prevent the seeds reaching the field. Good habits of eating, drinking, exercise, and of the mode of life in general, will keep the body in that healthy condition which will render the field in an unfavorable state for the growth of the seeds.

If these precautions do not succeed in the entire prevention of disease, they will, at least, very much lessen the chances of one's becoming a victim to it.

The proof of this is to be found in the excellent results in reducing the number of deaths from disease, and in limiting the spread of contagious forms, that have been obtained by the practice of these views during the last fifteen years, both in hospitals and dwellings, and on a still larger scale by the sanitary regulations of many cities.

Review Questions.

1. What is said of the relations of good air to health?
2. What of food?
3. What is one of the greatest dangers of health in connection with taking food?
4. What is said of drink?
5. What of the use of alcoholic drinks in excess?
6. What of the dangers from the "moderate use"?
7. What of the use of morphia?
8. Of tobacco?
9. What are bacteria?
10. Under what conditions do they grow?
11. What is the cause of all decay of organic substances?
12. What of harmless and dangerous bacteria?
13. What diseases are thought to be caused by some of the dangerous forms?

14. What is said of cleanliness in regard to danger from such diseases?

15. What of the importance of isolation of those sick with infectious diseases?

16. What precautions may be taken to limit the spread of disease?

17. How have these practices been proved to be beneficial?

INDEX.

The technical terms used in this book are fully explained at the places referred to in this Index.

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